INVESTIGATION OF NATIONAL RESOURCES

HEARINGS

BEFORE A

SUBCOMMITTEE OF THE COMMITTEE ON PUBLIC LANDS UNITED STATES SENATE

EIGHTIETH CONGRESS

FIRST SESSION

ON

INVESTIGATION OF THE FACTORS AFFECTING MINERALS, FUELS, FORESTRY, AND RECLAMATION PROJECTS

MAY 15, 16, AND 20, 1947

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INVESTIGATION OF NATIONAL RESOURCES

THURSDAY, MAY 15, 1947

United States Senate,
National Resources Economic Subcommittee
of the Committee on Public Lands,
Washington, D. C.

The subcommittee met, pursuant to adjournment, at 10 a. m., in room 224, Senate Office Building, Senator George W. Malone presiding.

Present: Senators Malone (presiding), Butler, Robertson O'Mahoney, and McFarland.

Senator Malone. The committee will be in order.

For the record, I will submit the motion creating this special subcommittee. It is the National Resources Economic Subcommittee of the Committee on Public Lands.

The motion is as follows:

> That a special committee to be composed of five members of the Committee on Public Lands be authorized and directed to make a full and complete study and investigation of the factors affecting minerals, fuels, forestry, and reclamation projects, cooperate with the proper committees and report at the earliest practicable date the results of its study and investigation, together with such recommendations as it may deem desirable.

The factors affecting the domestic production of minerals, fuels, forestry, fisheries, and agricultural products are many and varied.

These factors include import fees, excise taxes, tariffs, subsidies, quotas, imperial preferential rates, and the manipulation of currency systems by foreign nations, including operations of what is currently known as the sterling bloc. Also, production and marketing practices of the processing and manufacturing industries affect such production.

The general objective of the investigation is, first of all, to secure and analyze all the facts necessary for the formulation of a long-range policy governing our natural resources. Comprehensive economic and technological data will be collected and studied covering each basic natural resource found in the United States to determine, first, the ability of this Nation to produce for the domestic market; and second, the approximate differential in the cost of production of each specific product between this country and our principal foreign competitors due to the difference in the wage standard of living.

The aim of the committee is also to examine current practices and regulations affecting exports and imports so that a rational policy may be adopted by our Government with respect to imports which will tend to level the standards of living of other nations up to that of the United States rather than lowering our standard of living to their levels. This is an exceedingly difficult task since there are 55 countries in the United Nations Organization including our own—which means 55

different standards of living and 55 separate nations trying desperately to improve their status and trade relations with every other nation.

In order to facilitate the utilization of existing known resources and the exploration and development of new resources, it is essential to provide adequate financial incentives and to avoid excessive regulation which definitely retards the development of reserve supplies of minerals and materials secured from underground sources. On the basis of past investigations, it is evident that "prospectors" and "wildcatters" have continually increased the reserves of minerals and fuels over a long period of years, but that now an adequate incentive unit price not subject to change by Executive order is necessary to keep them risking their labor and money in barren drifts and dry holes in the process of developing new fields. The committee will investigate the various methods for providing adequate incentive to compensate for the hazardous nature of mining and will study the possibilities of flexible import fees as a means of equalizing costs of production between foreign and domestic producers.

A combination of factors is responsible for the great national strength and prosperity of the American Nation. The health and intelligence of our people, the wise and just political institutions adopted by our forefathers, the maintenance of a system of free private enterprise, and the abundance of natural resources have combined to make the United States of America the world's most powerful nation.

Of the many factors contributing to our national greatness, no single one can be said to be more important than our natural resources. Our rich and abundant agricultural and mineral resources have made possible a level of prosperity and a degree of national security never before attained by any other country. Some measure of the extent of these resources is seen in the 1946 figure showing the value of the output of our lands and mines. In 1946 the total value of the products of agriculture amounted to 23.9 billion dollars, and of our mineral production, nearly $9,000,000,000.

Since our national resources are not unlimited and since the consumption of these resources, both during World War II and thereafter, has been taking place at a greatly accelerated rate, the Special National Resources Economic Committee was created to make a comprehensive investigation of all the factors affecting production, development, utilization, and conservation of our mineral, fuel, agricultural, and forestry resources.

The committee has been instructed to cooperate with other appropriate committees of the Congress and to report, at the earliest practicable date, the results of its studies and investigation, together with such recommendations as it may deem desirable.

Whatever the specific details of any policy adopted covering our national resources, it will be universally agreed that the policy must be designed to accomplish two ends: (1) An adequate supply of agricultural and mineral resources sufficient to enable us successfully to ward off any conceivable attack by foreign powers; and (2) an ever-developing supply of resources which will permit steadily rising standards of living and general prosperity in the country. The conviction is growing in this country that domestic production in these fields should be maintained for national security, employment, and the main-

tenance of taxable property values, while assisting our less fortunate foreign neighbors.

To carry out the objectives of the investigation, the committee will study not only those factors which bear directly upon the production and utilization of our national resources, but indirect factors which exert an influence upon the domestic production and fabrication of mineral, agricultural, forestry, fisheries, and fuel products. Since international trade policies and practices exert a pronounced effect upon the domestic production of raw materials and the domestic processing and manufacture of such materials, the committee will investigate international trade policies and practices.

A careful study will be made of tariffs, subsidies, quotas, reciprocal trade agreements, imperial preference systems, and the manipulation of exchange rates. To secure all the relevant data desired by the committee, officials from the various Government agencies, including the State Department, Commerce Department, Justice Department, Army-Navy Munitions Board, War Department, Navy Department, Department of Agriculture, Department of the Interior, and Tariff Commission, will be invited to testify along with the producers of these products.

Leading representatives of the minerals, agricultural, forestry, fuels, and fisheries industries, as well as representatives from the industries processing such raw materials, will be invited to appear.

This morning we have the Secretary of the Interior, Mr. Krug, and he will be our first witness. He has a statement to make and a valuable report covering a considerable section of the mineral field that the Federal Bureau of Mines and the United States Geological Survey of the Department of the Interior has completed up to and including the calendar year 1944.

Mr. Krug.

STATEMENT OF HON. J. A. KRUG, SECRETARY OF THE INTERIOR

Secretary Krug. Thank you, Mr. Chairman.

When you kindly invited me over here the other day, you suggested, and I think wisely, that I bring along the men who do the work, and I have brought those men. They are here this morning and I want you to know that anybody in the Interior Department who can help your committee with the objectives it has in mind are at your disposal. They will be glad to appear at any time.

Senator Malone. Thank you, Mr. Secretary.

Secretary Krug. I have a brief statement introducing the work that the Department of the Interior does in this broad field that you are studying.

As you indicated, I also have a few reports which I would like to put in the record as I think they will be helpful to the committee in its deliberations.

Before making my statement, I would like to say that I listened intently to yours and I agree with what you had to say about the scope and value of our natural wealth.

I also am in hearty accord with the objectives of this committee. They are also the objectives of the Department of the Interior. We would like to feel that we can work hand in hand with you to get the best solutions for the people of the country.

As I have stated on a number of occasions during the past year, our natural resources problems have come forcibly to the foreground as a result of our experience during the war. The current shortages of many raw materials resulting from rapidly growing industry and improving standards of living have made us more aware of the reliance we must place on the basic resources which support the economic and social structure of our country.

It is well known that in some fields we cannot depend on old methods for the continuing flow of basic resources, but must give free rein to all of the native ingenuity and resourcefulness of our people, both in industry and in government.

As the war was drawing to a close, many were fearful that raw-material industries, which were, of course, greatly expanded to meet our war-production needs, would suffer a temporary relapse. These fears were unfounded and the demand for all production, from food through forest products and power to minerals, has reached higher than prewar levels and that for most of them has reached higher than the wartime levels. That reflects the normal industrial growth of the period, greatly accentuated by the war years.

Before the war, most raw-material industries operated in a buyer's market where the potential supply was greater than the demand. Today, the reverse is the case, and many important raw materials are in serious short supply as this committee knows.

This means many changes in policy and in approach to governmental operations. It means careful consideration of facts which must be diligently sought out, agreed upon, and thoroughly publicized.

I want to make clear, right at the outset, that the Interior Department recognizes that this is not just a governmental problem. It is one that will take the combined strength of our industry and our Government to get the answer needed as outlined in your preliminary statement.

The Interior Department is the agency of the Federal Government which has the primary responsibility for protecting, conserving, and developing the natural resources of the Nation. This responsibility covers minerals, metals, petroleum, gas, land, fish, game, water, parks, electric power, heat, and energy.

The Interior Department's annual report for the year 1946 outlined the over-all problems in these fields. In my opinion, it is the most comprehensive summary of the Government's natural resources problem available at this time.

I should like to submit it for your record and for the use of the committee. We have extra copies for the members.

(The report referred to is on file with the committee.)

Secretary Krug. It will be unnecessary to have it printed in the record.

The Department executes its responsibility in these many fields through bureaus and offices with many decades of experience.

I would like to list those various bureaus, although I know the committee is generally familiar with them:

First, the Geological Survey is a fact-finding agency which collects and distributes information about the mineral and water resources of the Nation. It conducts research and exploration in geology and related fields and prepares topographic and mineral maps. In addi-

tion, it supervises mineral operations on leased public and Indian lands and on the Naval Petroleum Reserve.

Second, the Bureau of Mines is responsible for activities in mining, metallurgy, and mineral technology. It promotes safety in mineral industries and investigates problems of mining and the preparation and utilization of minerals. In the field of conservation, it experiments in methods of ore reduction and refining. It operates pilot plants for the development of new industrial uses for minerals and is engaged in a large synthetic-fuels-development program.

Third, the Fish and Wildlife Service protects and fosters our natural resources of fish, birds, and game. It administers the Federal game laws for the private hunters and fishery regulations for the commercial fishermen.

Fourth, the National Park Service administers the national parks and monuments and other reservations created by Congress to preserve scenery and natural and historic objects for the use and enjoyment of all the people.

Fifth, the Bureau of Reclamation constructs and operates multiple-purpose reclamation projects which provide water to irrigate arid and semiarid lands and hydroelectric energy for industry and farm uses.

Sixth, the Bonneville Power Administration markets the electric power produced at Bonneville and Grand Coulee Dams in Oregon and Washington. It now provides about one-half of the power used in the Northwest.

Seventh, the Southwestern Power Administration is just getting started in the Southwestern States. At the present time that is rather a small operation.

Those are the principal operating bureaus of the Department having responsibilities closely related to the subject you are interested in, Mr. Chairman.

In addition, I have in my own office several groups that work in this field. I have, for example, the Oil and Gas Division, which is responsible, under Executive order, for coordination of the policies and administration of Federal activities related to oil, gas, and synthetic fuels, and which serves as a central liaison office providing a point of contact whereby the oil and gas industries can advise the Government on their normal functions.

Next, the Office of Land Utilization, which coordinates land classification, use, and management programs to insure a consistent departmental policy on land use.

And, third, the Division of Power, which supervises the various power operations in the operating branches of the Department.

The subordinate directors and staff members of the divisions and offices are all available for you, and they will be pleased to appear on call. A great many of them are here this morning. I thought you might want to get immediately to the bottom of some subjects of which they have special knowledge.

One of the most important natural-resources problems is that of the status of our mineral resources. The Geological Survey and the Bureau of Mines have just completed a 3-year study of the problem. As you know, Mr. Chairman, preparation of this material has made a heavy drain on their time and resources and also on those of the industry, but the product, in my opinion, is the best study and analysis of our situation in the minerals field that has ever been done.

But, even so regarding it, I think you will find in studying this report that an important conclusion, if not the most important, is that we still have a lot to learn in this field, and I am pleased that this committee has taken up this study.

As I look upon this, while it may be temporarily the bible of our mineral resources, it requires a lot of refining and we will look forward to working, not only with your committee but with all the industries affected, to see if we cannot come out with results upon which there is general agreement.

In saying that, I recognize that there has been controversy for many years as to what the facts are concerning our minerals, but I am not discouraged about finding the facts and using those facts to develop the program we need to meet the objectives of your committee—assuring the country a supply of minerals and metals for its expanding peacetime production, and for meeting another emergency if we have to meet another one.

Mr. Chairman, I would like to read the transmittal letter in this report, if I may, and I would like to submit the report in the hope that your committee will find a way of printing it. We have not, so far, been able to find the funds for that purpose.

This is a foreword signed by me, introducing this report:

The United States has been endowed with vast mineral resources, whose equal in quantity and variety has not yet been found in any other like area of the world.

Possession of these resources and ability to utilize them have made possible the preeminent industrial position of the United States and its unexcelled standard of living. Our deposits of coal, iron ore, petroleum, and many other minerals essential to our industrial civilization thus comprise one of the Nation's greatest assets, vital to every citizen in the land.

Mineral resources are, unfortunately, exhaustible and through the years they have been depleted at an ever-increasing rate. During the recent war the United States was hard pressed to obtain mineral raw materials adequate to meet military and civilian requirements. Once again, it was evident that the Nation's storehouse of minerals lacked several important commodities without which our industrial machine could not function.

Some of the mineral industries, from which ample supplies were derived in the past, were unequal to the task of meeting the war-inflated demands. These experiences naturally caused anxiety as to the extent to which the mineral resources of the Nation had been exhausted.

The United States Department of the Interior, being charged with the responsibility of promoting the conservation and development of the country's natural resources, is deeply concerned about the status of the mineral industries of the Nation. Recognizing the need for taking stock and appraising the outlook for the future, the Department, through its Bureau of Mines and Geological Survey, undertook an appraisal of the United States mineral position early in 1944. The results of the study are presented in this volume.

The report reveals that the United States is by no means a "have-not" nation in those minerals that are basic to the maintenance of its kind of industrial society. However, its resources are deficient in several important industrial minerals and the outlook for major improvements in most of these areas is not favorable.

Thus, continued dependence on foreign sources for supplies of these commodities is indicated. Although the group includes minerals that are vital to the machine economy in the past it has represented dollarwise a minor part of our mineral requirements.

That is a very important point and I think we should all keep it in mind. While we do need some of these minerals and they are important to us, they represent only a small portion of the total dollar value of all the raw material needs of our country.

This country's tremendous reserves of many things which are vital, will last a long time. For example, in the case of sand and gravel, where Russia is almost horribly deficient, this Nation has almost unlimited reserves. That is the case for many other raw materials as well.

This country can maintain varying degrees of self-sufficiency in a third group of minerals which includes some in which virtual independence from foreign sources has been enjoyed for several decades. In some of the minerals of this group the effects of depletion of known resources are being reflected in production patterns where deficiencies exist or are developing. Steps must be taken to insure adequate supplies in times of emergency.

In general, America's mineral outlook is favorable, but it is obvious that a dynamic program of research and exploration must be pursued if new sources are to be developed to supply future needs. This nation can no longer afford to continue the policy of letting nature take its course.

The data presented in this report are not to be taken as a measure of the Nation's ultimate mineral wealth. Such an appraisal is precluded at this time by incomplete knowledge of the country's resources. The report does present a factual summary of the present mineral position of the United States based on present knowledge. It is believed that the study will prove to be a valuable guide to legislators, Government officials, producers, and consumers of minerals, and others concerned with problems of mineral supply.

That is the end of my introductory statement.

(The report referred to is on file with the committee.)

Secretary KRUG. I would like to say in connection with this report—I am not saying this for your advice because you know it, but I am saying it for the advice of others who might use it—that parts cannot be pulled out of context. The report must be considered as a total report. It would be very misleading for somebody to take out a table saying that copper is short or lead is short without having the background that goes with that particular conclusion.

We have found that by bitter experience. Such practices are terribly misleading, and for that reason it is important that information in this report on various minerals be taken as a whole and thoroughly understood, and that particular sentences or tables not be deleted from it.

(The report appears at the end of this volume as appendix I.)

Senator O'MAHONEY. Have you had the details, Mr. Secretary, of the recent announcement from Russia of a program of the Soviet Government to conduct an extensive geological and mineral survey of all the Russian areas?

Secretary KRUG. Senator O'Mahoney, I do not have the details of it. All I have is probably what you saw: A newspaper dispatch from Russia saying that they were doing that.

I think it is a certainty that they are. They must realize the dependence of future prosperity on raw materials, the same as we do over here.

Senator O'MAHONEY. The investigations of the special committee on petroleum in the last Congress developed clearly the fact that within the Russian area—Russia in Asia, particularly—there are vast possibilities for the discovery of petroleum and we know very little about it except that the testing program in the United States has been carried on intensively for many years, whereas in Russia, which is apparently geologically favorable for the discovery of petroleum, the work is only beginning.

I mention this as emphasizing the great importance of our taking every possible step to develop our own resources.

Secretary Krug. Yes. I think it is vital to the Nation that we do everything within our power to develop resources within this country. Expanding peacetime needs, and anticipated continuing needs at the new level, are so great that they will require everything we can do, and over and above that, we ought to have a cushion for any future emergency.

Senator Butler. I would like to just interrupt the Secretary at this point. I have to go to an executive committee meeting of finance shortly and I did want to ask the Secretary and also the chairman if, in the course of a hearing, you are going to investigate the possibilities of our resources in connection with synthetic products made from surplus grain crops, surplus farm crops.

You hinted at some such thing in your preliminary statement, Mr. Secretary, and I think it is one phase of the subject that might be explored rather thoroughly in connection with the survey that you are talking about.

Senator Malone. I want the record to show that Senator Butler is chairman of the Public Lands Committee that created this Special National Resources Economic Committee. We are glad to have him with us this morning to start the hearings.

In answer to your question, Senator Butler, I had intended to not only discuss it with members of our subcommittee, but with you, that as we go along with the different departments, we will include the production of synthetic products from all sources.

I know that they have certain plans for the development of synthetic materials including a plan to develop petroleum products from coal and oil shale. We know that we have almost unlimited reserves of oil in coal and oil shales. We know the Agriculture Department has made considerable headway in the development of other synthetic materials from agricultural products, and we had intended to get not only all the work that had been done up to date from the Secretary of the Interior and his assistants but from the other departments as well.

Senator Butler. The Secretary referred to the oil supplies, mineral supplies of the world being exhaustible. It certainly is true. We hear rather frequently mention made of the rather early exhaustion of our supplies of petroleum—such materials as we get from the earth.

We learned during the recent war that we can make products that will substitute for petroleum, for instance from the crops grown from the surface of the soil that are inexhaustible and I hope during the course of the hearing, Mr. Chairman, that that point is thoroughly stressed.

Senator O'Mahoney. Perhaps, Mr. Chairman, it may be appropriate for me to remark that the stock-piling law which was enacted by the last Congress not only authorized the Department of the Interior to make extensive studies for the development of strategic and critical materials from our mineral resources but it also authorizes the Secretary of Agriculture to do the same with agricultural products.

That is the point in which all of us who represent agricultural areas, as well as mineral areas, are very much interested. And, since the chairman of our committee announced that he is going to the Finance Committee, I cannot refrain from saying that it would very much aid the development of our natural resources if we do not give away too

much money in reduced taxes to those who do not need the reduction.

Senator BUTLER. I will carry that message to the Finance Committee, Senator. [Laughter.]

Senator MALONE. Mr. Chairman, referring to Senator Butler, I do not think we will go too far into the Finance Committee's business, but we do hope—I hope and the members of this committee hope—that through these hearings we will be able to correlate the necessary information so as not only to point to our own reserves of such products, but determine how to maintain our production in the face of wide differentials between the wage standards of the countries of the world and to determine our trade relations with them.

I have no preconceived conception of how this should be done—we are out to get all the information we can and to consult with the entire committee as often as possible as to the scope and recommendations, not only in the matter of development and exploration of our known raw materials but perhaps in some respects to the legislation that affects such developments such as the Securities and Exchange Commission Regulations and Operations. All of these things will be taken up in order.

Dr. SAYERS. Mr. Chairman, it might be pertinent and might be interesting to Senator Butler to know that the act sponsored by Senator O'Mahoney on synthetic fuels provided for cooperation with the Agriculture Department to make synthetic fuels from agricultural products, and that is being carried out at the present time at their laboratories and will further be carried out in cooperation with the Department of the Interior through the Bureau of Mines.

Senator O'MAHONEY. Within the limit of the appropriation.

Dr. SAYERS. Within the limit of the appropriation. And, I thank you for that, sir. (Laughter.)

Senator MALONE. A further general statement I would like to make at this time is that, in the opinion of the chairman, there are several reasons why a domestic production is desirable. First, of course, it is the national security. Second, is employment.

Third, taxable property to maintain our Government and to secure the money necessary to carry on our Government and development and to do this in competition with the other 54 nations—we say 55 nations, at least that many are members of the United Nations—it is necessary ultimately to deal with the problem of the different wage standards and costs of living if we are to maintain profitable production.

It will be necessary to work out a flexible import fee to meet the changing differentials of cost of production in this country and the principal competitive foreign nations in each case.

You may proceed, Mr. Secretary.

Secretary KRUG. Mr. Chairman, I would like to have the Director of the Geological Survey and the Director of the Bureau of Mines proceed to tell you about the work of their respective departments.

Of course, preceeding that, if there are general questions on departmental policy that the committee would like to ask me, I would be glad to try to answer them.

Senator MALONE. Senator O'Mahoney, do you have any questions?

Senator O'MAHONEY. I wondered, Mr. Secretary, if you cared to put into the record here the program, if it has been developed, which

the Department would like to carry out with respect to, first, the survey of our resources and, secondly, the development of a policy in compliance with the stock-piling act.

Secretary KRUG. Senator, I would like to answer that generally, and then to have Dr. Wrather and Dr. Sayers give you the details concerning the specific work that we have proposed.

When I left the War Production Board at its liquidation in November 1945, I was deeply impressed concerning the need of the program that the chairman just outlined for this committee. When I returned to public service as Secretary of the Interior in March of 1946, I made it a first order of business to sit down with the Geological Survey and the Bureau of Mines and, I might say, with the House Appropriations Committee, at that time, and outline what I thought had to be done in a sequence of time periods in which I thought it could be done, practicably.

Senator O'MAHONEY. In your position with the War Production Board, you had ample opportunity to learn how expensive it was to the United States that it had not carried on the stock-piling recommendations made by Bernard Baruch after World War I?

Secretary KRUG. Yes, sir.

Senator O'MAHONEY. Because of our failure to develop our own resources, we were compelled to spend more than would otherwise have been necessary to acquire the materials and minerals that we had to have to wage the war.

Secretary KRUG. That is right. It was not only a horrible cost in money but it was perhaps even more serious in man-hours of the most important men in the country who, instead of applying their knowledge and experience to producing more materials, had to spend a good part of the first 2 years, during which the Nation was preparing for the war and carrying it on, in doing things we well could have had in hand before the outbreak of hostilities.

Senator O'MAHONEY. In other words, I take it that it is your position that the United States cannot afford to go back to the methods and policies of prewar days with respect to the development of our natural resources here in the United States?

Secretary KRUG. That is my very strong feeling.

As this committee knows, we had better than 2 years to get ready for the real test in this war. That was certainly a very happy coincidence and it was just about that. The 2 years were desperately needed to do these things that could have been done before to get enough aluminum, enough copper, enough lead, enough fabricating facilities to back them up so we could produce airplanes, tanks, ships, guns, and ammunition.

In the next war I do not feel that we are going to have any 2-year period of preparation. We are going to have to be prepared in advance for the emergency. For that reason, I felt strongly when I came into the Interior Department a year ago that everything that could be done to find out about our mineral resources and what we could do with them in this country certainly should be done at the earliest possible date.

Senator O'MAHONEY. That, of course, involves a very broad program by the Bureau of Mines and the Geological Survey before we can even begin to equip ourselves to produce these very necessary materials?

Secretary KRUG. Yes, sir. It starts with those two bureaus, because they furnish industry with vital information it needs in going forward with its plans, which, in the end, of course, actually accomplishes the mining and processing of raw materials.

We devoted a good part of the last year to stepping up our planning in topographic mapping, survey, and geophysical work, in pilot-plant operations, synthetic fuels—in all of these fields and we worked with the Army and Navy on the stock-piling program.

This year we presented to the Congress an expanded program for Survey to get ahead with this tremendous problem. We also presented a somewhat enlarged program for the Bureau of Mines, but concentrated on the thing that would help us measure our natural wealth.

Obviously, without that stepped-up program years and years will go by before the basic information is available to Congress and industry to deal with this problem. The amounts of funds involved are very small.

It seems to me ridiculous that in a country of this size and with this strength and our dependence on these minerals and raw materials, the comparatively small amounts necessary to do the spadework, the initial work necessary for all industry and for Congress to move ahead, are not made available promptly and the work is not done as rapidly as possible.

By "as rapidly as possible" I mean as soon as competent, qualified people can be secured to make the maps and the surveys and the information can be digested and published so that Congress and industry will have it.

I would like to have Dr. Wrather and Dr. Sayers outline the work of their respective organizations in connection with this broad general problem.

Senator MALONE. Mr. Secretary, perhaps you know, and if you do not know offhand, you can get it from your assistants, you mentioned stock piles of strategic and critical minerals and materials. In regard to present copper and lead and zinc supplies, stock-pile supplies or stocks on hand, are they greater now or less than before?

Secretary KRUG. They are virtually nonexistent. During the last 2 years, Mr. Chairman, it has been impossible to meet all of the normal peacetime demands, and to have acquired anything for stock piling would have just reduced the supply available to industry.

Senator MALONE. We know they have been depleted, but this depletion was from our wartime supplies. How do they compare with the supplies on hand when we first began to prepare for World War II? Do you happen to know?

Secretary KRUG. I do not have the figures, but my guess is that the total on hand is somewhat higher than at that time. But in terms of industrial needs, the amounts on hand are much smaller.

I have had many people from industry who are using these materials come to me and say that their supplies are below their minimum practical working inventory, so their day-by-day operations are affected by their not having enough copper or enough lead or enough zinc.

Senator MALONE. Do you have any questions, Senator Robertson?

Senator ROBERTSON. No; not at present.

Senator MALONE. Mr. Secretary, we will accept this report for our files and, as I understand it, you have 39 of what you consider the most important minerals covered in this report?

Secretary KRUG. I think that is right.

Dr. SAYERS. That is right.

Senator MALONE. I did inspect the report and I want to compliment your people on the preparation of it. It looks to me like a very good start on a survey of the minerals in this country.

Now, we will hope, however, to get the material on additional minerals from your Department and any place we can get them and then we hope that the committee can find ways and means of publishing a rounded-out report of the entire mineral list.

That, of course, is quite an undertaking as you know, but I believe that the Senate would recognize the importance of it once we brought it entirely up to date.

I notice we will have to add perhaps 1946 and maybe a start of 1947. Maybe we could do that before it was published.

I want to thank you, Mr. Secretary, for the information that you have given us. Is it Dr. Sayers that you would like to call now?

Secretary KRUG. Perhaps Dr. Wrather should go next.

Senator MALONE. Dr. Wrather, Director of the United States Geological Survey.

Dr. Wrather, do you have a prepared statement?

Dr. WRATHER. I have a prepared statement.

Senator MALONE. You may proceed and make any remarks you desire.

STATEMENT OF DR. W. E. WRATHER, DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY

Dr. WRATHER. It would perhaps be helpful to offer a brief outline of the functions of the Geological Survey. The Geological Survey has been since the beginning preeminently a natural-resource bureau. At the time of its inception in 1879, it covered practically the entire field of natural resources. Since that time, various functions have been segregated to form new bureaus, among these the Bureau of Reclamation, the Forest Service, the Grazing Service, and the Bureau of Mines.

The Survey functions through four branches.

1. Topographic Branch, which has the obligation to complete the topographic mapping of the United States and its possessions. Such maps are basic to any natural-resource development, and they are a prime requisite for any development in mining, industry, water-resource development, and so forth.

2. The Geologic Branch, which is charged with the responsibility for the development of new techniques and scientific activities which form the inevitable background for mineral-resource studies. It is also concerned with the exploration for new sources of supply and evaluation of mineral resources in place.

3. The Water Resources Branch, which is a fact-finding organization concerned with the over-all evaluation of the water resources of the Nation. Its activities fall into three categories—surface water, underground water, and quality of water.

The first is primarily an engineering activity concerned with the evaluation and measurement of stream flow; the second is more complex in nature and involves hydrology, engineering, and geology; the third involves determination of minerals in solution and the solid mat-

ter carried in suspension in surface streams. All these are but phases of the evaluation of the total water resources of the Nation. Fair-weather streams merely represent the excess run-off while the underground reservoirs receive and retain the water which percolates through the soil and enters through cavities.

4. The Conservation Branch which is concerned with the mineral classification of the public domain and administration of the mineral leasing law. The activities of the Conservation Branch are conducted in the 17 western public-land States.

I suppose that the emphasis on this occasion is primarily on mineral resources, and is, therefore, chiefly concerned with the activities of the Geologic and Conservation Branches. The Geologic Branch is concerned with the earth sciences. Geology is in reality a federation of earth sciences since it involves a number of related fields, such as paleontology, stratigraphy, mineralogy, chemistry, physics, etc. All these implements are required for mineral studies.

Exploration for new sources of mineral products and geological evaluation of known deposits is one of the chief functions of the Geologic Branch. Certainly one of the most important activities of this Branch is areal and structure mapping which furnishes the background for determining the localization of mineralization. Areal geologic mapping has always been one of the chief activities of the Geological Survey. But it has never yet been able to conduct mapping on a scale at all comparable with the need. It is estimated that the surface geology of only about 10 percent of the country is adequately mapped on suitable scales at the present time. I might add that it will undoubtedly never be necessary to map all of the country on identical scales. but there are very large mapped areas in the country which are mapped on entirely too small scales to meet present needs.

Senator O'Mahoney. What is the special advantage of aerial mapping?

Dr. Wrather. Areal, spelled "a-r-e-a-l," mapping shows distribution and relationship of different rock formations. We have learned from experience and study that mineralization occurs in certain specific environments.

In other words, mineral deposits never occur by accident; they are the result of geological processes. Mineralization follows a pattern. When a hunter goes out for squirrels, he does not go where he could only hope to find quail; and that argument prevails in geology.

There is an environment in which one normally looks for certain types of mineral deposits, and geology is primarily a science of reducing the areas of prospecting to more and more specific areas of greater promise.

The efforts of the Geological Survey are to define clearly the areas in which there is the highest probability, the best geological prospects, of finding mineral deposits, hoping that as soon as the favorable geological factors are made clear industry will then follow in and do the necessary next steps of exploration.

Senator O'Mahoney. What is the specific fact that makes the aerial a most desirable means of doing that?

Dr. Wrather. Senator, I think perhaps——

Senator O'Mahoney (interposing). I am asking you these questions because we had experience before the Appropriations Committee a couple of years ago in getting authority to use an airplane.

Dr. WRATHER. Yes. I am not speaking particularly of mapping from the air. I used the word "a r e a l" which is the geologists' term to denote geologic mapping by regional areas.

Senator O'MAHONEY. I misunderstood you. I thought you were talking about "aerial."

Dr. WRATHER. Yes; the words are so similar they are easily confused.

Senator O'MAHONEY. I did not get the diphthong.

Dr. WRATHER. That mistake is very frequently made, Senator.

Senator MALONE. Dr. Wrather, to keep the record straight, the aerial mapping is simply an additional map to assist you in your work? Is that correct?

Dr. WRATHER. Yes, now speaking of photography from the air.

Photography from the air is becoming more and more important in geological investigations because we are now able to decipher a certain amount of geology directly from aerial photographs. Aerial photography facilitates geologic mapping. In topographic mapping, we are going more and more to the use of aerial photographs for the basis of making maps. Aerial photography is now basic procedure in the topographic branch.

Does that answer your question?

Senator O'MAHONEY. Yes, indeed. You have got me back on the track. [Laughter.]

Dr. WRATHER. The use of these words is oftentimes quite confusing because they sound so much alike when spoken; but one refers to areas, and the other, to the air.

Senator O'MAHONEY. I confess I was puzzled when you said areal mapping was always an objective in a geological survey.

Dr. WRATHER. Yes.

In the orderly development of any mineralized district the first step is the making of a geological map.

Another important activity is the development of new skills and techniques suitable for prospecting. For many years there have been practically no important mines discovered from surface outcrops. The exposed rocks have been fairly well explored and it seems that surface prospecting for location of important new ore deposits must henceforth be highly scientific and thorough if it is to be effective. Huge areas of the West which, so far as we now know, are potential mineralized areas, are covered with valley fill, with slide rock, with recent volcanic lava which successfully mantle and obscure the underlying rocks. Geologists confidently expect such areas will ultimately yield substantial mineral wealth. If we are to make progress in the discovery of hidden ore deposits in such areas we must resort to every available technique for securing geologic information, such as geophysics, geochemistry, or other as yet undeveloped new methods. A considerable step forward has recently been made by the Geological Survey in the adaptation of the air-borne magnetometer as a prospecting device. This task of exploration of blind areas, I consider to be an inevitable step in the mineral devlopment of the country. It will require the highest scientific skills available, a substantial expenditure of money and will necessarily be time consuming. However, it must be done if we are not to sit supinely by and be content with the obvious depletion of our presently known mineral wealth.

I believe we can no longer delay a comprehensive and systematic effort to better evaluate our mineral resources. I rather object to the use of the term "mineral inventory" because this connotes a more specific degree of accuracy than I believe is obtainable in the mineral industry. I think, nevertheless, it will be entirely possible to arrive at a relative evaluation of mineral resources which will offer a satisfactory basis on which to predicate mineral policies. Such an evaluation can be expressed in terms of proven ore and ore which can be reasonably inferred on the basis of geological reasoning.

Senator MALONE. Dr. Wrather, an inventory rather indicates inventorying the known supplies?

Dr. WRATHER. That is it. Cans of tomatoes and sardines on the shelf that can be counted.

Senator MALONE. While your survey, as you have so ably described, would aid in locating further supplies——

Dr. WRATHER (interposing). That is it.

Senator MALONE (continuing). Of minerals——

Dr. WRATHER (interposing). That is it; yes, sir.

Senator MALONE (continuing). Do you believe that as much as anything else, the encouragement of venture capital in this field is necessary?

Dr. WRATHER. I think it is; yes, sir. We must have extensive prospecting.

Senator MALONE. In other words, there are two steps. First, the survey you speak of which would be valueless without the encouragement of venture capital and prospecting and mining?

Dr. WRATHER. Yes, sir.

Such estimates should never carry the connotation of being the ultimate reserve of the Nation. It will probably never be possible to forecast with any degree of definiteness the as yet undiscovered mineral wealth of the country. Such consideration has been given due weight in the study which is before you. The present study should be considered only in the light of the philosophy expressed in the opening chapters. It is based upon admittedly incomplete data but with due consideration to its limitations. I think the volume will offer a point of departure for later, more complete reviews of the future.

Senator MALONE. At that point, doctor, is it intended that you continue your studies as you have in the past, and you would no doubt have reports then in that connection, additional reports, you could furnish the committee?

Dr. WRATHER. Yes, sir. I think that this situation is dynamic. Any such estimate soon becomes antedated. New discoveries, accelerated rates of withdrawal, all those things complicate the picture as to what the current net reserve is.

I think the wise thing from a national standpoint would be to periodically cast up the balance sheet in the light of the best information as of that date. The task is never finished. Any such balance sheet is soon out of date.

Senator MALONE. I note even in your report here that 1945 is the latest date in most instances that you have in this report.

Dr. WRATHER. Yes, that is true.

On the whole, I believe there is fairly general agreement on certain features of our mineral situation. There will be little disagreement as to those minerals in which we are almost entirely deficient. Likewise, there will be little disagreement as to those which we have in such abundance as to give no present-day concern. There will probably always be disagreement as to adequacy of supplies of those commodities in the middle ground, namely, those which we are capable of producing in larger or smaller proportions of our domestic requirements.

Senator MALONE. There, again, doctor, the cost per unit of production enters largely.

Dr. WRATHER. Oh, yes, cost is a very important factor of the problem.

Senator MALONE. Where certain minerals might not be available at a certain price per unit, if that cost or price were to be raised, they might become available.

Dr. WRATHER. Such considerations are very important, Senator, and that is why these figures must be used in the light of statements made in the beginning chapters of the volume.

Natural resources alone are never the answer. Brazil, with all of its wealth of iron ore, with its deficiency of suitable coal, and with inaccessibility of the deposits which necessitates expensive transportation—that magnificent resource of raw material is of nowhere near the same value as a much smaller reserve, exploited by highly technical and competent personnel, suitably located to transportation and subject to economical utilization.

The value of resources is largely determined by competency of the technical talent available for their exploitation.

Senator MALONE. Take, for example, a specific mineral like tungsten, where a supply might not be available at all in the country here at, say, $14 or $15 a unit. But, if it goes up, $30 or $35 or $40 a unit, apparently there has been plenty of tungsten available.

Dr. WRATHER. That is equally true of quicksilver, which at the normal price of, say, a dollar a pound or $75 a flask, renders our known domestic reserves quite inadequate. Now, at the war price of better than $200 a flask, numerous widely scattered low-grade deposits became available immediately as a resource. The effective reserve under different conditions would show wide disparity. The same ore deposit at one time may not be valuable as a resource and at another time it may become invaluable.

Senator MALONE. Your previous statement that any available supplies must be evaluated in the matter of price per unit at the time evaluation was made is important.

Dr. WRATHER. That is true.

Senator MALONE. And there again, as I brought out in an earlier statement, regarding that differential of cost of production between this country and other countries of lower wage standards, unless that differential is made up, the production in this country would suffer, would it not?

Dr. WRATHER. Yes, sir.

I furthermore believe that the type of information which can be supplied by the Geological Survey and the Bureau of Mines is urgently needed as a background for the guidance of the stock-piling program

recently enacted into law. It is particularly unfortunate that the activities of both these bureaus threaten to be seriously curtailed at this time when there is every reason in the national interest of expanding rather than contracting them.

I would like to call attention to the fact that the foregoing discussion applies primarily to the economic phases of the mineral situation. If the Geological Survey is to perform its task effectively it must be extensively engaged in research, and this research should be carried forward irrespective of whether it offers promise of immediate economic application. It should be in a position to experiment with geophysical principles which may offer the basis for new techniques of exploration.

Senator MALONE. I would like the record to show at this point that Senator Robertson sat with us during the hearing.

Dr. WRATHER. It should carry on investigations in earth sciences such as glaciology, volcanology, paleontology, without immediate expectation of profitable practical application since a wider and sounder knowledge of all these related earth sciences may be expected in the future to find economic uses. The entire country is at present sold on the idea that scientific research is not only justified but even imperative. Only by vigorously prosecuting research can we retain our preeminent position among world powers. It is a matter of equal importance both in peace and in war.

The Survey is a scientific and technical bureau. By far the greater part of its staff is comprised of specially trained personnel. It is axiomatic that effective scientific work cannot be performed by mediocre talent. It is also equally evident that an organization to attract and hold the high-grade talent required must have reasonable stability from year to year. It cannot be expanded and contracted at will without a great loss in efficiency and waste of funds. The program should be carried forward from year to year in an orderly fashion. Both the Survey and the Bureau of Mines should be given support to expand to a point where they are capable of giving to the Nation the service which Congress has decreed they should render.

Senator MALONE. Do you have any other comments?

Dr. WRATHER. Nothing further unless you have questions.

Senator MALONE. Senator McFarland?

Senator MCFARLAND. No.

Senator MALONE. Dr. Wrather, we appreciate your appearance here this morning and if you have any further information to offer at any time I hope you will notify the chairman.

Dr. WRATHER. Thank you, sir.

Senator MALONE. Dr. Sayers, Director of the Federal Bureau of Mines, under the Secretary of the Interior.

Dr. Sayers, do you have a prepared report?

Dr. SAYERS. Yes.

Senator MALONE. You may make any comment you care to.

STATEMENT OF DR. R. R. SAYERS, DIRECTOR OF THE BUREAU OF MINES, DEPARTMENT OF THE INTERIOR

Dr. SAYERS. If it is agreeable, I will summarize this statement in order to save your time.

Senator MALONE. That would be very good.

Dr. SAYERS. This statement covers the organization and functions of the Bureau of Mines, together with the authorizations under which it acts.

It calls attention to the fact that there are five principal branches in the Bureau of Mines, and those five branches have to do with the efficient and effective production, the conservation of the minerals of this country, and the safety and health of those that are producing.

All of these branches affect the production of minerals in this country as can be determined from the newspapers or any of the people that are in the industry. Each and every one of these branches contributes to the success of whether we do or do not produce.

It is a matter of economics, quite frequently, as well as health and safety, as to whether we are successful in the production of a particular material.

The report here has been adequately presented to you by the Secretary and by the Director of the Geological Survey, and I subscribe, I will assure you, to the statements that he made in regard to the activities of his organization and to the Bureau of Mines; I wish to bring out, if I may, that we are working in very close cooperation as is indicated by the fact that the document submitted by the Secretary is a product of the joint efforts of the personnel of the two organizations which have enjoyed the support of the industry in this work. Such close cooperation, we believe, is essential to solution of problems confronting industry and government in this yield. The personnel that guided the preparation of this particular document are here—Mr. Pehrson, from the Bureau of Mines, and Mr. Bannerman, from the Geological Survey. They can go into details if it is so desired.

May I go off the record a moment?

Senator MALONE. Yes, sir, surely.

Off the record.

(Discussion off the record.)

Senator MALONE. Now, you may proceed.

Dr. SAYERS. The Secretary called attention to the fact that we were deficient in information in regard to minerals at the beginning of the war and there is no one in the room who is not well acquainted with that fact. But, nevertheless, the members of the Geological Survey and the Bureau of Mines during the period, to my knowledge, from 1922 and probably before, to 1939, were trying to get something done along this line.

They did not succeed until 1939 when the emergency was evident and it was too late to do it well and in an orderly way.

Work of this character should be a continuing program. It is not a thing that can just be done and be a closed book after that.

You mentioned that a material which is just a mineral today may be an ore tomorrow. There may be a number of different reasons for this. One of them you mentioned was rise in price. Another may be progress in technology. We may be able to produce a particular thing by a cheaper method. That is one of the jobs that the two organizations working together need to do—metallurgy and pilot-plant work, particularly.

Senator MALONE. As an example of that, your department worked out a method of utilizing low-grade manganese ores and electrolytic manganese. I cite that as an outstanding example, but there are

many others. This work was done by the Nevada division of the Federal Bureau of Mines at the University of Nevada.

And the pilot plants are to determine economic feasibility.

Dr. SAYERS. That is correct, sir, and that is very important.

We have certain minerals in this country in enormous deposits. Some pilot plants, constructed at the expense of the Government, were completed, but have never operated. We, at least, should complete the investigations. We should try to find out whether those processes will work at whatever price it may be, because they may prove to be cheap in the end.

Senator MALONE. Where are those pilot plants located?

Dr. SAYERS. One is in South Carolina, one in Laramie, Wyo., and one of them is in Oregon.

Senator MALONE. And, they are completed?

Dr. SAYERS. They are completed, but they have not operated. They should operate on the materials that are available, and there are large quantities of those.

Senator MALONE. What type of materials?

Dr. SAYERS. Anorthosite is one of them. That is in Wyoming. Others include materials that are similarly high in alumina, such as clays or clay-like materials.

Mr. Ralston, who is here, can go into a great deal of that detail if you want it, but I just mentioned these pilot plants as illustrations of important things that need to be carried forward.

I think we ought to carry on such work on a much larger scale and the amount of money necessary to do this is comparatively very small.

Senator MALONE. Mr. Ralston can give us the necessary information?

Dr. SAYERS. He can give it to you. I can give it to you, but I think it is better for Mr. Ralston to do so because he has more detail and his is more accurate. Mine is more general.

Senator MALONE. That is a good example of other materials and other metallurgical experiments in the production of substitute materials.

Dr. SAYERS (interrupting). Mr. Ralston will call your attention to the fact that we have recently produced titanium metal from titanium ore, that that is the fourth most prevalent ore in the earth's crust which we have for producing a structural metal, and that we have recently produced zirconium as a ductile metal, many uses of which, although apparent, have not been worked out.

He will also call your attention, going back to the manganese, to the additional uses that can be made of metallic manganese. Resources for making that type of manganese in this country are abundant.

I would like to again emphasize that we believe that the manuscript submitted is the best information that is today available on at least 39 of the critical or strategic minerals.

Senator MALONE. Your specific point is in line with my general statement? A mineral or a material is available, we know about it, and no doubt it has been there for thousands of years, but suddenly it becomes valuable through some metallurgical process that can be worked out for utilizing it.

Dr. SAYERS. That is right, sir.

Senator MALONE. Dr. Sayers, a general question as to what studies your Bureau may have made or are engaged in at this time in marketing the different metals might be helpful. Have you made such studies?

Dr. SAYERS. To a limited extent only, because funds are not available, although we have suggested several different times that such studies be made. I do not know whether you want to put it in the record or not.

Senator MALONE. I think this is a good place for it, and I agree with the general line of questioning of Senator O'Mahoney that this is the place to find out not only the data you have but the data and material that we would require to come to some logical conclusions about the cost.

Dr. SAYERS. We have done some work along that line. We can give you a statement as to what we estimate it will cost. That can be placed in the records.

Senator MALONE. We would be very glad to have it.

Dr. SAYERS. I am quite sure Mr. Pehrson can give you details of it, if you so desire, and figures can be given you for each part of it.

Senator MALONE. Do you have any questions, Senator O'Mahoney?

Senator O'MAHONEY. Unfortunately, I was called out but did you make a preliminary statement?

Dr. SAYERS. I did, sir, but that was on the organization. This is on the work of the organization, with which you are well acquainted.

Senator MALONE. The general field covered by the Bureau and their work.

Senator O'MAHONEY. Did you discuss the answer to the question that I asked Secretary Krug about the program which the Bureau of Mines has in view to carry out the stock-piling act?

Dr. SAYERS. Not in detail, sir.

Senator O'MAHONEY. Let us have that picture. I think it is very important. Congress has passed a law and it really meant it and I think that even though there has been a certain change in the Eightieth Congress from the Seventy-ninth Congress, that it still is of a mind to proceed with the development of our resources.

(The information requested is furnished herewith:)

The Bureau of Mines has undertaken but few general studies of marketing problems due to the fact that no funds have been appropriated for this specific purpose. A few studies on marketing of coal have been made using funds transferred from other agencies. The Bureau has repeatedly requested appropriations for this purpose. The 1948 budget request included the following description of and justification for broad studies of this type.

With the termination of the war the problems of reconversion, full employment and the postwar operation of industry have become realities that must be met promptly and effectively. This objective cannot be realized unless full information on the status quo of industry and adequate analyses of past trends and future outlook are available. Before the war many gaps existed in the factual record of the mineral industries and there were virtually no facilities for analyzing past performance and forecasting future needs. In recent years the war agencies have expanded to meet these deficiencies insofar as services were required for war purposes, but virtually no improvement has been made in the permanent services of the Government operating in the field of mineral economics. The requests for additional funds under previous headings will take care of the fact-finding phases of the postwar program. The increase requested for this item will provide the necessary staff for special and periodic analytical studies of a regional and national nature such as are required for mineral planning and administration by

the Department of the Interior, Bureau of Mines, and State agencies and for preparing the estimates of the outlook for employment in the mineral industries that will be needed in compiling the President's annual budget of employment to be submitted to Congress.

Only a meager start has been made in filling this need. With the funds requested herewith it is proposed to establish a Washington unit of sufficient size to initiate the type of services required by the executive departments and to facilitate correlation of the Bureau's domestic activity in economics and statistics with that of State agencies and to give better service to mineral producers and consumers throughout the country.

The unit will study basic trends in the industrial economy as applied to mineral production and demand. Forecasts of mineral requirements will be made and estimates prepared on the quantities likely to be supplied by domestic sources and imports. Such fundamental analysis is essential to forecasting the outlook for employment and is basic to national planning designed to maintain industrial prosperity and to provide orderly development and utilization of domestic resources. Many basic factors that have a direct and important bearing on the mineral economy of the Nation and employment must be studied before sound forecasts can be made. These include transportation and other costs, tariffs, cartels, wages, price relationships, etc. Understanding of these factors also is essential in planning and administering the Bureau's over-all program for developing the Nation's mineral resources, and reports resulting from such studies will have wide utility in Government and industry circles.

Dr. SAYERS. I have indicated that I think that is true, also, Senator, and I brought out as an example of that the importance of having at least our pilot plants working—for instance, the aluminum pilot plants. We ought to know what we can do with those plants, already constructed.

That was just an indication, but going into the general subject, there should be a program of exploration so that we may know what we have, the Geological Survey and the Bureau of Mines working in coordination. They work as a team and they are doing that right along.

Senator O'MAHONEY. Could you tell us briefly for the record some of the work which was undertaken by the Bureau as a result of the war in order to produce the materials which were needed for the war but which have now been suspended because of the false assumption in some quarters that we can revert to a prewar standard so far as mineral development is concerned?

Dr. SAYERS. In 1939 an act was passed by Congress which was a stock-piling act and an authorization to the Geological Survey and the Bureau of Mines of $2,000,000 was made.

Senator O'MAHONEY. That was the original law?

Dr. SAYERS. The original law.

Senator O'MAHONEY. Sponsored by Senator Thomas of Utah?

Dr. SAYERS. That is correct, sir; $600,000 of that was to be expended by the Geological Survey and $1,400,000 by the Bureau of Mines. It was to be a coordinated program. It was visualized as that and that was what was undertaken.

The Geological Survey carried on their geological studies, recommending the probability or possibility of finding minerals of different types in particular areas. We started out with seven of the strategic minerals. Those seven strategic minerals were the ones we were presumed to work upon.

As time went on, we found that we did not have as much of some of the others as we thought. In a little while, those critical minerals were merged with the strategic to the place where we had about 39 considered to be critical or strategic.

We carried out studies on tungsten, manganese, chromium, nickel—on the whole 39 as a matter of fact.

Many of these were found in larger quantities than were known before. Tungsten is an outstanding example. Reasonably large, high-grade deposits of it were located in Idaho. Other deposits were located in California, Colorado and other States. The one in Idaho has been pretty well mined out. Another deposit of high-grade tungsten was found in North Carolina.

There is reason to believe that other needed deposits of ore can be found, and it is studies of that character that should be continued. We have many requests for them, because the present need, as you pointed out a little while ago, Mr. Chairman, is for some of those that are not considered quite as strategic. The Secretary pointed out that these, for which we are largely dependent on foreign sources, may not be as important to our economy from a dollar standpoint, as lead or zinc or copper, for example, on which we have been placing emphasis during the last year or two. Other projects have been suspended because we do not have funds with which to do the work.

Senator MALONE. Is it not a fact, Dr. Sayers, that taking tungsten as an example—you have just cited that there are mercury and other minerals that are classed as strategic in that we have difficulty in producing what we need for our own use—is it not a fact that when the price per unit goes up, we do discover additional supplies continually, and even at this time there are more reserves of tungsten than there were even before the First World War? Is that not a fact?

Dr. SAYERS. Yes; I am quite sure that it is, if you will put in the word "known"—known reserves.

Senator MALONE. In other words, it is a question of not only your experience and your mapping and your studies, then, but it is a matter of encouraging investment of venture capital in the business?

Dr. SAYERS. Yes; I think that would be true.

I am very much concerned for the sake of our economic security in this country as well as our military security, that we know what we have and how we can put it into a useful form.

I am of the opinion that if we follow through even on that basis, we will probably be producing in this country a great many of these minerals which we are discussing and have described in this report; that we will be producing in quantity.

Senator O'MAHONEY. There were various projects which were undertaken during the war, like the development of alunite in Utah, the processing of alumina clays, the great development in the Northwest in which the mines participated.

Now, much of that was done through the investment of RFC funds in Government plants. The Department of the Interior, however, has a specific mandate from Congress under the Stock-Piling Act. I think it would be well for you to take the time to prepare and insert in the record a list of activities of the Bureau of Mines which were carried on during the war but which will have to be abandoned if you do not have the funds, and the activities which ought to be carried on if Congress can be persuaded to supply you the funds, giving the reasons for each.

I ask you to prepare it because I think it is of sufficient importance that I do not want you to answer extemporaneously.

Dr. SAYERS. I think, sir, it should be prepared and I would be very glad to do it.

Senator MALONE. I agree with Senator O'Mahoney and we hope you will be able to do that and submit it for the record.

(The information requested is attached hereto:)

(Statement entitled "Strategic and Critical Minerals—Geological Survey" transmitted May 20 to Senator Malone's committee.)

(Four branches of the Bureau of Mines are engaged in work having a direct bearing on the strategic mineral problem as outlined in Public Law 520. There are presented herewith brief summaries of such activities and programs of the Metallurgical Branch, Mining Branch, Economics and Statistics Branch, and the Fuels and Explosives Branch:)

BUREAU OF MINES, METALLURGICAL BRANCH

SUMMARY

The information requested by the Subcommittee on Mineral, Fuel, and Forest Resources of the Senate Committee on Public Lands is attached, as follows:

A. A listing of the activities of the Metallurgical Branch during the defense and war periods;

B. A statement of accomplishments under such activities, dealing with each major subject and many of the minor commodities. The Branch was called on for help of some kind in connection with almost every known metal or mineral and a complete statement is obviously impossible within the time and space available;

C. A list of justifications of projects that can be carried on under Public Law 520 of the Seventy-ninth Congress, section 7 (a) in connection with stock-piling and preparation of the mineral industry for another emergency. The known domestic ores, as well as those likely to be found, will probably be low-grade, complex, or otherwise unsatisfactory for immediate use and require milling, other physical processing, and metallurgical and chemical study to devise means for their economical extraction, stock-piling, and marketing.

The best kind of a stock pile is the know-how of treating the mineral resources that are available. This stock pile of knowledge must be accumulated now—not when an emergency is upon us. The Metallurgical Branch can best serve in the function of accumulating know-how about every type of deposit that offers reasonable possibilities. Testing each one by known processes, devising when necessary suitable new processes, and developing substitutes for the items that are in short supply constitute the program of the Metallurgical Branch.

A. ACTIVITIES CONDUCTED DURING THE NATIONAL DEFENSE AND WAR PERIODS

The following list of projects conducted by the Metallurgical Branch of the Bureau of Mines has been restricted to those of primary importance.

Manganese production:
- (*a*) Pilot-plant operation, Boulder City, Nev.
- (*b*) Alloy development, Salt Lake City, Utah.
- (*c*) Cooperative industrial tests, Washington, D. C.

Chromium production:
- (*a*) Process studies and pilot-plant operation, Boulder City, Nev.

Cobalt production:
- (*a*) Process studies and pilot-plant operation, Boulder City, Nev.

Magnesium production:
- (*a*) Carbothermic magnesium studies, Pullman, Wash.
- (*b*) Cooperative magnesium investigations, Ford Motor Co., Dearborn, Mich., and Albany, Oreg.
- (*c*) Magnesia from Olivine, Norris, Tenn.
- (*d*) Secondary metal recovery, College Park, Md.

Alumina and aluminum production:

- (*a*) Lime-soda sinter research on alumina production, College Park, Md.
- (*b*) Solvent extraction process for aluminum sulfate production, College Park, Md.
- (*c*) Pederson electric furnace research on alumina production, Norris, Tenn.
- (*d*) Sulfuric acid process for alumina production, Rolla, Mo.
- (*e*) Ammonium alum process for alumina production, Salt Lake City, Utah.
- (*f*) Potassium alum process for alumina production, Boulder City, Nev.
- (*g*) Secondary metal investigations, College Park, Md.
- (*h*) Bauxite beneficiation studies, Rolla, Mo.
- (*i*) Fundamental metallurgy of alumina and its salts, Berkeley, Calif.

Titanium production:

- (*a*) Process studies and pilot-plant operation, Boulder City, Nev.
- (*b*) Metal fabrication, Salt Lake City, Utah.
- (*c*) Alloy investigations, Salt Lake City, Utah.

Zirconium production:

- (*a*) Process studies and pilot-plant construction, Albany, Oreg.

Iron and steel production:

- (*a*) Sponge-iron research:
  - (1) Laramie, Wyo.
  - (2) Johnstown, Pa.
  - (3) Pittsburgh, Pa.
  - (4) Raleigh, N. C.
  - (5) Minneapolis, Minn.
  - (6) Salisbury, N. C.
- (*b*) Iron-ore beneficiation:
  - (1) Tuscaloosa, Ala.
  - (3) Minneapolis, Minn.
- (*c*) Ferro-alloy pilot plant, Redding, Calif.
- (*d*) Fundamental metallurgy of iron and steel, Pittsburgh, Pa.
- (*e*) Open-hearth steel studies, Raleigh, N. C.

Ore dressing:

Research and testing was conducted on virtually every industrially significant mineral in the United States including the ores of aluminum, antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, chromium, cobalt, columbium, copper, iron, lead, manganese, magnesium, mercury, molybdenum, nickel, phosphorus, radioactive elements, tantalum, thallium, tin, titanium, tungsten, vanadium, zinc, and zirconium.

Nonmetallics.

- (*a*) Miscellaneous nonmetallic studies, Norris, Tenn.
- (*b*) Utilization of clay research, Tuscaloosa, Ala.

B. Accomplishments in National Defense and War Activities

It is impossible to include a full list of Bureau reports on the various accomplishments described below, as space does not permit, but in each instance a typical reference is given and a copy of the publication is attached.

Manganese

The Metallurgical Branch developed and pilot-planted to conclusion an electrolytic manganese extraction process, adapted to treatment of low-grade ores of the types most plentiful in the United States. The output of the pilot plant made possible the use of the manganese in the 5-cent piece, thereby conserving use of the strategic and critical metal nickel. It was also supplied in large trial lots to progressive industrial enterprises and was successfully used as partial substitute for nickel in stainless steels. A commercial plant for electrolytic manganese, therefore, received orders and repeatedly increased the size of its plant until its operation cost came below the price of nickel. The Government pilot plant was then shut down; the infant industry had been established.

Mining exploration work on manganese deposits frequently opened up ores of low grade that required special work. Ore-dressing methods were tested on the manganese ores of the Nation and in many cases satisfactorily beneficiated them to give concentrates of acceptable grade. Sometimes the concentrates had to be sintered to bring them up to acceptable metallurgical grade. Others required a more profound metallurgical treatment and a method of matte smelting of manganese was developed and proven through the pilot-plant scale. A hydrometallurgical process using the solubility of manganese dithionate as a means of

extraction was developed and successfully pilot-planted too late to be of value in the war, and a nitric acid process of leaching certain manganese ores was also carried through pilot-plant scale.

It would appear that this method might well be adapted to the synthesis of battery-grade manganese dioxide for use in dry cells, but this is a job that yet remains to be done.

The role of the Bureau of Mines in metallurgical research is typified by this commodity. A new process, a new industry, and alternate raw materials are now being used in our national use pattern as a result of the Bureau's efforts. In addition the provision of a substitute metal for nickel in a variety of uses increases our industrial flexibility.

Reference: Bureau of Mines Report of Investigations, No. 3815, Utilization of Three Kids Manganese Ore in the Production of Electrolytic Manganese: June 1945, 78 pages.

Chromium

Most of the chromite ore within the United States is impure and requires special treatment, and a few yield to gravity, flotation, and similar dressing procedures. Bureau of Mines tests resulted in erection of a number of such plants early in the war. When impurities constitute part of the chromite molecule itself, more profound metallurgical treatment is necessary and most of the United States chromite is of this type. An early job done on these chromites was their chlorination, and after purification it was possible to reduce chromic chloride to pure chromium metal sponge by means of hydrogen.

A more fundamental job was done on reducing the associated iron to metal or lower oxide, soluble in dilute sulfuric acid. Extraction raised the grade of the residual chromite and corrected the unfavorable iron : chromium ratio to one satisfactory to the electric smelters of ferrochromium. This job was completed in a pilot plant toward the end of the war and did not get into general practice, but is now included in the plans of several postwar industries.

Yet another scheme involved complete sulfuric acid dissolution of chromite, purification and crystallization of chrome alums thus obtained, and then electrolytic deposition of pure chromium metal from a solution of pure chrome alum. A pilot plant was erected at Boulder City, Nev., and was just getting into operation at the end of the war. It is still in operation on reduced scale due to dwindling appropriations. The pure electrolytic chromium is superior to chromium reduced by means of silicon or aluminum and should make possible the manufacture of better stainless steel and other chromium alloys needed in guided missiles and in many industrial alloys. This job should be pushed to a conclusion because the process makes possible the use of low-grade domestic ores, increases security, and may be used in building up stock piles of very acceptable chromium, which is ready for immediate use by industry. The stock piling of electrolytic metals has a dual advantage in the availability of the material and the accumulation of power and labor, which is always in short supply during time of war.

A very large amount of service work was done by the Bureau laboratories during the exploration program before and during the war. Some of the low-grade chromite of the States of Washington and Oregon was also found to be of acceptable grade in the preparation of chrome brick, an indispensable item in the iron and steel industry.

Reference: Bureau of Mines Report of Investigations, No. 3834, Beneficiation of Montana Chromite Concentrates by Roasting and Leaching: February 1946, 37 pages.

Nickel

Nickel occurrances of sufficient magnitude to justify exploration were known in the States of Washington, Oregon, and Missouri, but the ores were either low-grade or complex, requiring metallurgical research. The war was well advanced before any pilot-plant study could be instituted.

Shallow alloy melting furnaces had to be used in the attempt to smelt ores, whereas the deeper smelting-type furnaces were needed. A tentative conclusion was reached on the two large deposits in Washington that these high-iron, nickel-bearing ores probably could be selectively reduced to pass most of the nickel into a layer of nickel-iron alloy and leave most of the iron unreduced in the slag. A larger furnace became available toward the end of the war and this conclusion was confirmed, but the war ended before the knowledge could be utilized and control of the operation achieved. A larger deposit of nickel ore

in southern Oregon was also partially explored and a start made on smelting its nickel and iron content. The job is unfinished. The same is true of the complex nickel-cobalt-copper, etc., ore of southeast Missouri.

Reference: Bureau of Mines confidential report, not published to date.

Cobalt

A very promising new district of cobalt-copper ore was opened through exploration in central Idaho. Presence of arsenic was a complicating factor. By the end of the war, a good process had been developed and a small pilot unit started at Boulder City, Nev. Decreasing funds slowed down the work and now this plant can be operated only a portion of the time. This is another unfinished job. The supercomplex southeast Missouri nickel-cobalt ore, as mentioned above, still remains unsolved. It received attention too late in the First World War and then again in the Second.

Reference: Bureau of Mines Report of Investigations, No. 3882, A Study of Certain Factors in the Hydrometallurgy and Electrodeposition of Cobalt: November 1945, 43 pages.

Magnesium

A carbothermic magnesium extraction process was developed on the small scale before the Kaiser plant in California was initiated and a small pilot plant was built and operated. Some of its technique was adopted by Kaiser after disastrous explosions of magnesium dust took place, oil being used as a quenching medium. The need of "goop" for magnesium incendiary shells made it unnecessary for the Kaiser plant to go beyond this point and the mixture of oil and magnesium powder did yeoman service in the war. This pushed into the background the need of completing the recovery of magnesium as fused metal ingots from this product and the war ended before a definite conclusion could be reached. The Kaiser plant operated on the batch system and the Bureau process was a continuous system not yet reached in the Kaiser plant. The Bureau has limped along, approaching successful pilot-plant demonstration, unable to complete the work with the limited funds available.

An electrolytic cell to convert magnesium oxide direct to metal was developed in Bureau laboratories and proven on one full-size cell at the Boulder City, Nev., pilot plant. It makes unnecessary the intermediate formation of magnesium chloride. This improved process was completed about the end of the war. A job on extracting magnesium oxide from dolomite was completed at Boulder City, and a second pilot plant on the same process erected and tried at Plymouth Meeting, Pa., with industrial cooperation. The oxide was for use in the ferrosilicon reduction process, widely used but abandoned at the end of the war because of cost. A second process for recovery of magnesia from dolomite was devised at Pullman, Wash.

The olivine rocks (dunites) of the Appalachians and of the far Northwest were also studied as sources of magnesia and magnesium chloride, and a pilot plant erected at Norris, Tenn. The operation of the pilot plant has just been terminated, too late for use in the war. The olivines always carry small amounts of nickel and it had been intended to study its coincident recovery, but funds and time did not permit. Further work along this line is justified in order that the nickel and some associated chromium might be added to the list of recoverable products which are in critical domestic supply.

Reference: Bureau of Mines Report of Investigations, No. 3823, Construction and Operation of the Dearborn Magnesium Pilot Plant: August 1945, 26 pages.

Alumina

This is the oxide of alumina, which if obtained in pure form is easily converted into metal. A small fund was obtained for pilot test of a highly advertised French process just before the war started. Results were disappointing, but pointed toward an improved process. Later, ample funds for alumina development were made available when sinkings of the bauxite boats in the Caribbean were endangering the Nation's supply of imported ore. Intensive exploration for domestic bauxite revealed great quantities of off-grade material, but disappointing quantitites of the commercial grade. This low-grade material and the clays and other high-alumina minerals loomed as the only promising domestic source. A commercially exploited process using alunite as raw material failed early in the war, and while the Bureau had several alternative processes that might have been pilot-planted, the failure of this particular process had shaken the faith of the War Production Board, and the others were not approved. However, the Bureau was busy developing two alkaline proc-

esses, the lime-sinter process and the lime-soda process, as applied to both clays and anorthosite rock. Too late in the war to be useful, pilot plants were authorized through the War Production Board on contracts made by Reconstruction Finance Corporation with commercial enterprisers. One, after reaching the point of a shake-down run, wherein the need for certain changes developed was stopped in its tracks (Harleyville, S. C.). The other plant (Laramie, Wyo.) was completed, but was stopped before it could operate. An acid-type process, using ammonium sulfate as an extracting chemical was separately developed by the Bureau of Mines and the Chemical Construction Co., Columbia Metals Co. as proposed operator, erected a plant at Salem, Oreg. In partially completed stage at the end of the war, it was ordered to produce ammonium sulfate, badly needed for fertilizer purposes of war use of ammonium compounds in explosives. It also remains to be operated but here again funds are refused.

The large development of low-grade bauxite, contaminated with clay, in Arkansas caused erection of a pilot concentrating plant at Bauxite, Ark., at the end of the war to see if it would not be possible to mechanically concentrate good-grade bauxite and leave a clay containing some bauxite for other uses or one of the alumina extraction processes mentioned above. Ten stock piles of ore representing the variations of raw material in one county were worked. The ores of the other county are known to be higher in iron and more complex and were on the agenda for the bauxite pilot plant. Cutting of funds for pilot plants in 1948 (63 percent cut) has made necessary the abandonment of plans to operate this unit.

Reference: Bureau of Mines Report of Investigations, No. 3903, Concentration of Bauxite for Milling in the 50-Ton Bureau of Mines Pilot Plant, Bauxite, Ark.: August 1946, 25 pages.

Tungsten ores

During the exploration work for strategic, critical, and essential minerals, many tungsten ores were found which required concentration. Most of them yielded to milling processes and permitted preparation of commercial-grade concentrates by use of gravity or froth flotation methods. No difficult problems demanding detailed study and pilot plants were encountered.

Reference: Bureau of Mines Report of Investigations, No. 3801, Summary of Bureau of Mines Exploration Projects on Deposits of Raw Material Resources for Steel Production: March 1945, 33 pages.

Molybdenum ores

The same as has just been said about tungsten applies.

Reference: Bureau of Mines Report of Investigations, No. 3801, Summary of Bureau of Mines Exploration Projects on Deposits of Raw Material Resources For Steel Production: March 1945, 33 pages.

Mercury ores

Many tests were carried out, similar to those on tungsten and molybdenum ores with satisfactory results. For all three metals commercial operators built and operated satisfactory plants.

Reference: Bureau of Mines Information Circular, No. 7299, Bureau of Mines Exploration of Mercury Deposits to June 30, 1944: November 1944, 14 pages.

Antimony ores

The United States continued short on antimony and some deposits were discovered, concentrated, and worked. One large deposit in Idaho had a gold content that entered the antimony and an electrolytic refining process had to be devised. It is in use by the operator.

Reference: Bureau of Mines Report of Investigations, No. 3676, Exploration for War Minerals (Through Fiscal Year 1942): March 1943, 44 pages.

Vanadium

War exploration in Idaho and Wyoming opened up a find of vanadium in the phosphate beds. The ore is low grade but the gross amount of vanadium shown over a large area proves it to be the biggest known deposit in the world. Two processes for the extraction of the vanadium and accompanying phosphate have been worked out, one of them on a test-plant scale. It is worthy of pilot-plant development on its own merits, but has the additional virtue of promising a vanadium supply from domestic materials, as to date domestic production of vanadium is only part of the total needed. If any electric furnaces are built in

the area to produce phosphorus, it is probable that the vanadium will pass into a ferrophosphorus byproduct that normally forms in such furnaces. The recovery of the vanadium from the ferrophosphorus should also be studied. Repeated attempts to get funds for taking these last steps in the vanadium recovery have been fruitless. The job should be finished.

Reference: Bureau of Mines Report of Investigations, No. 3679, Smelting of Vanadium-Bearing Titaniferous Sinter in an Experimental Blast Furnace: January 1943, 24 pages.

Titanium and zirconium

These two metals have remarkable properties of resistance to corrosive attack. Titanium is comparable to stainless steel and can thus replace the strategic chromium and nickel required for stainless steel without any alloying. Supplies are large.

Zirconium is a metal comparable to tantalum, which was largely imported and even can compete with platinum for many purposes. The Bureau of Mines adopted a titanium-producing process seized by the Alien Property Custodian from German owners, improved it, and began production on pilot-plant scale of better ductile titanium than any one else has produced in the United States. Most of the titanium produced by others is not even ductile or workable due to impurities. Our pilot plant has become the source of supply of the research departments of the armed forces and many industrial establishments that are now studying and developing uses of the metal. The zirconium development is not as far along, but occupies a similar position. This highly important work will go on at a slowed pace with available appropriations.

Reference (titanium): Bureau of Mines War Minerals Report, No. 197, Titanium as a Structural Metal: 1944, 11 pages.

Reference (zirconium): Bureau of Mines War Minerals Report, No. 7341, Survey of Literature on the Metallurgy of Zirconium: February 1946, 50 pages.

Iron

The looming exhaustion of the Lake Superior iron-ore fields within the next generation has caused concern to the iron and steel industry, the truly basic mineral industry of our present economy. By this is meant the iron ore of direct smelting grade. Huge supplies of low-grade materials that require beneficiation are available in the same area, but the materials vary in complexity and ease of treatment. Most of the larger producers as well as a number of private inventors are at work. Considerable funds have been allotted to the Bureau of Mines to work on this problem. While its necessity was accentuated by the war, the problem is, however, a continuing one. The Bureau has some definite important accomplishments.

Coking coal for iron blast furnaces became a critical factor during the war and much of the Bureau work was along lines that would not require the use of coke and permitted the use of a wide variety of fuels. The sponge-iron processes are prominent among them.

First of all, the iron ores that can be concentrated by mechanical means have been studied. Many were of such a texture that they required fine grinding to liberate iron minerals from gangue. For these ores five different flotation processes were developed and several different grinding processes employed to prepare the ore for flotation. Gravity concentration of the coarser sizes of iron minerals was greatly improved by study of hydraulic classification and invention of a new open-bottom classifier of large capacity and low water requirement. Iron ores must be produced at low cost and treatment processes must be simple. Some of the iron ores could not be freed mechanically of gangue until after their iron oxide had been reduced to sponge iron, but attrition grinding and magnetic separation then added to efficiency of gangue rejection.

The Bureau of Mines some years ago developed several sponge-iron processes, but unsolved problems remained that made them undesirable. The chief objection was to sulfur content. During the war several ways were found of preventing sulfur getting into the sponge iron or rejecting it before the operation was finished. These had the advantage of simplicity and low cost and it can now be said that the sulfur problem in sponge iron is essentially solved. Sponge iron of satisfactory grade to use as a melting stock in open-hearth and electric furnaces has been made by three main types of processes: (1) Rotary kilns like cement kilns; (2) brick kilns; and (3) reduction with gases instead of solid fuels, the best furnace for the work being a vertical shaft furnace. Where the feed was in fine dust size it was found possible to agglomerate it into little balls

by rolling the mass with proper addition of water. This method demanded the presence of part of the iron ore in exceedingly fine particles to make a "mud" binder that hardened on being dried and heated. The brick kilns were best adapted to making a superpure sponge iron if a pure ore is used as raw material. The product is of the quality of the Swedish sponge iron imported for over 30 years for the cutlery industry, and always available in smaller quantities than were demanded.

Western ores of a great variety were also studied and the processes detailed above were applicable. An alloy melting plant at Redding, Calif., was erected to make quality steels from sponge iron and has had its first year's run. The iron and steel program, from the standpoint of extractive metallurgy, is about half done, but curtailment of the budget for fiscal year 1948 has caused recess or abandonment of most of it and only the most critical phases of it can be funded with an appropriation 37.5 percent of that requested. Here is definite important unfinished business of national significance.

Reference: Bureau of Mines Report of Investigations, No. 3841, Manufacture of Sponge Iron in Periodic Brick Kilns: December 1945, 38 pages.

Lithium ores

During the defense period, two methods of concentrating low-grade lithium ores, of which a large domestic supply is available, were developed and proven in small pilot plants. Also two extractive metallurgy processes were likewise proven. When contracts for lithium plants were needed the technology was available and all four processes were used and succeeded in supplying lithium metal and its compounds. This is another case where peacetime proved to be the best time to do work expeditiously.

Reference: These studies were conducted prior to World War II, although the results were extensively used.

Clays

Nearly every State has clays of some sort that might be used for more than brick making, and not all of the humbler clays are suitable even for that. A clay team set up at Tuscaloosa, Ala., several years ago has never been properly funded. By degrees, a study of clays has resulted in the partial development of methods for determining their suitability for various purposes. Just how well a clay is adapted for a certain use calls for quantitative examinations, and this program has only limped along because of inadequate funds. The suitability of clays for use as foundry sand binder has been worked out and the methods are available for testing. The powers of certain clays to bleach mineral, animal, and vegetable oils have been under study for 2 years, and a forthcoming paper will report the results of two lone workers. At the rate of progress in the past and the lower rate possible under decreased appropriation, it will take 50 years to complete such a program. Certain clays not known to be available in the United States are imported. It is quite possible that fractions taken from some of the domestic clays will fill these needs. Funds for fractionating research have been repeatedly requested, but never allowed.

Reference: Bureau of Mines Bulletin, No. 451, part I, Syllabus of Clay Testing: 1943, 35 pages.

Lightweight aggregate

Reinforced concrete demands steel and concrete buildings require structural steel around which concrete is poured. By use of lightweight aggregate the whole structure weighs less, and less steel is required. Certain clays, shales, and slates bloat when heated to the proper temperature and make a cheap lightweight aggregate. The perlitic lavas of the West do the same thing. Superlightweight aggregate gives thermal and sound insulation, and plasters, partition blocks or slabs of this material can cheapen construction and at the same time make more serviceable and comfortable structures. Lightweight aggregate can be substituted to advantage for cinders in cinder block or concrete block for which the supply of cinders is dwindling as power plants convert more and more to coal-dust firing. The recess in building during the war has built up a demand that cannot be satisfied for some years under costs that have increased to an outrageous extent for normal methods of building. The Bureau has sought funds repeatedly for work on lightweight aggregates, but been refused and has had to confine itself to small-scale laboratory experiments. Yet this work has increased the utility of the perlites and has recently brought to light a "baking powder" that can be mixed into any common clay and cause it to bloat

when heated. This activity should be immediately funded to meet the present building crisis.

Reference: Burau of Mines Information Circular, No. 7364, Perlite Source of Synthetic Pumice: August 1946, 11 pages.

Talc

This useful mineral was in short supply in the grades required by the radio-insulator industry, namely, block talc that can be carved in complex shapes for the big insulators and radio-ceramic grade needed for molding small insulators. Both grades had been imported due to insufficient knowledge of the domestic resources. An exploration and testing program was instituted during the defense years and met with success. The ceramic grade was found in about 30 widely scattered spots, many of them in California. A few occurrences of block talc were found, but it became apparent that a synthetic block is the only answer domestically. The continuous tunnel kiln of the Bureau at Norris, Tenn., was pressed into service early in the industrial building program and for 9 months produced insulators for radio sets on tanks and planes until the industries had gotten their new kilns built and assumed the load. The problem now remaining with us is the production of synthetic block talc.

Reference: Bureau of Mines Report of Investigations, No. 3804, Survey of the Suitability of Domestic Talcs for High-Frequency Insulators: April 1945, 58 pages.

Feldspar

The lush feldspar deposits of the Appalachian Mountains have been the main source. They are approaching exhaustion. A satisfactory method for separating feldspar from associated mica and quartz was worked out and pilot-planted through industrial cooperation during the defense years. Two mills were built during the war, based on this work, and functioned usefully when the long haul from the West would have placed too heavy a burden on the railroads. One of the lithium plants previously mentioned also recovered feldspar.

Reference: Bureau of Mines Information Circular, No. 6974, Annual Report of the Nonmetals Division, Fiscal Year 1937: October 1937, 18 pages.

Corundum

This abrasive mineral was entirely imported or made synthetically from bauxite in electric furnaces. For the uses that could not be filled by the synthetic product imported material was employed to the extent that it could be obtained. A search for corundum disclosed a number of small domestic deposits, mostly low grade, and milling methods were applied to them. The only commercial venture based on one of these came too late in the war and was not well managed so that it failed to be effective.

Reference: Bureau of Mines Information Circular, No. 7295, Corundum: September 1944, 18 pages.

Flake graphite

This commodity had been in short supply during the First World War, and promised to be short again. During the early part of the defense period, preceding war, this problem was studied intensively and a satisfactory froth-flotation process improved to the stage of usefulness. As soon as needed, five concentrating plants were built by contracts under the Reconstruction Finance Coporation and went into operation. They were closed in 1944 when supplies of the larger flake from Madagascar were again coming through safely. Pilot plants should be built and operated between wars or before wars if they are to show greatest utility.

Reference: Bureau of Mines Report of Investigations, No. 3397, Flotation and Agglomerate Concentration of Nonmetallic Minerals: May 1938, 63 pages.

Mica

Sheet mica was in serious shortage. Exploration revealed a considerable amount. Its trimming and splitting are done by hand and the technologic problems involved the utilization of the scrap and of the small-size mica occurring with it. Concentrating processes have been applied successfully for making flake mica, delaminating booky mica, sizing according to large diameter and according to small diameter. Some of these have already gone into commercial use.

Reference: Bureau of Mines Report of Investigations, No. 3558, Froth Flotation and Agglomerate Tabling of Micas: February 1941, 14 pages.

Kyanite

There are several kinds of kyanite and one of them is strategic due to the small supply in the United States. It is known as Indian kyanite, a specially hard, dense material that retains considerable strength on calcining. Since refractory brick are made from most of the kyanite, it is important. Exploration revealed a little of this type and tests proved it satisfactory. A topaz deposit in South Carolina was also proven a satisfactory substitute, but due to its fluorine content that vaporizes in the furnaces and becomes a nuisance, not much was used. Satisfactory processes of making the full substitute for Indian kyanite were worked out; at the present time the Navy is asking for a quantity of Navy brick for furnaces on naval vessels and funds are being sought to meet this demand.

Reference: Publications pending.

Sillimanite

This is a twin mineral to kyanite, chemically, but is markedly different in physical properties. No reliable supply was known in the United States until exploration revealed large deposits in South Carolina and Georgia. Tests by gravity tabling flotation have shown that it can be cleaned to an acceptable grade. It is one of the ingredients in the above-mentioned Navy brick now wanted for trial use on destroyers. Funds for its immediate development are sought.

Reference: In technical press as non-Bureau publication.

Miscellaneous metals and minerals

Many minor materials are of high importance. Industrial diamonds are an example. This Nation's potential for producing diamonds is almost zero. Substitutes are needed and work now being conducted on the small scale has brought to light very promising hard materials that can be synthesized.

Asbestos is another strategic mineral of which we have little and the synthesis of spinning asbestos would be a boon. Quartz crystals were sought all over the world for use in radio frequency control and the domestic supply suitable for the use was far too small. The Bureau did its share of the work in examining and testing minerals that might meet military needs, but space forbids detailed descriptions of what has been accomplished: suffice it to say that there are about 40 useful metals and 500 industrial minerals dealt in commercially that could be mentioned.

C. Estimates for Work Under Public Law 520, Seventy-ninth Congress

In Public Law 520, Seventy-ninth Congress, section 7 (a), "The Secretary of the Interior is authorized and directed to make * * * investigations concerning * * * preparation, treatment of ores and other mineral substances * * * which are essential to the common defense or the industrial needs of the United States * * * to devise new methods for the treatment and utilization of low-grade ore reserves and to develop substitutes for such essential ores and mineral products * * *."

In conformity with this directive, the following list of projects has been prepared. It is conceived to devise means of recovery and preparation of materials suitable for the stock piles called for in the act. It must be pointed out that the best stock pile is probably the know-how on proper ways of supplying strategic, critical, or essential raw materials or substitutes therefor. If research and pilot plants must be erected after an emergency has arisen, time is short, materials and qualified experts are difficult to acquire and as past experience has proved, the preparations made have been too little and too late. If the know-how is available, the appropriation is made for erection of a producing plant, instead of awaiting the results of research and development. Peacetime is best for the orderly prosecution of such work and if done over a number of years instead of under pressure a far more effective job is accomplished at less cost.

Some projects can probably be finished in 1 year, but where pilot plants are involved they may not be completed until the end of the fiscal year ahead, and many of them require several years of cut-and-try, correction and improvement before they can be pronounced satisfactory. Continued liasion with the Army and Navy Munitions Board will uncover other problems to replace the ones finished in short time, and it is believed that a 5-year period is a reasonable one to anticipate for the proper execution of these important security projects.

LIST OF PROJECTS

1. Manganese dioxide, battery grade.
2. Chromium, electrolytic and sponge.
3. Nickel-bearing ores of Northwest.
4. Cobalt-nickel ores of Missouri.
5. Iron and steel.
6. Titanium extraction and uses.
7. Zirconium, extraction and uses.
8. Vanadium, extraction and uses.
9. Magnesium-nickel-chromium ores.
10. Alumina, abrasive, from low-grade bauxite.
11. Kyanite-sillimanite refractories.
12. Talc, synthetic block or substitute.
13. Industrial diamond substitute.
14. Thalium extraction and uses.
15. Gallium extraction and uses.
16. Lightweight aggregate.
17. Metallurgical testing of all exporation samples.

Manganese dioxide, battery grade

Objective.—To provide for a domestic supply of manganese oxide of suitable grade for dry batteries.

The problem and its significance.—Exploration during the war showed little manganese dioxide ore suitable for making dry batteries and war demands far more batteries than are required in peacetime. At a recent meeting of the Army and Navy Munitions Board Committee on the subject, it was agreed that a more intensive exploration and testing of ores within the country was worth while, but it is more likely that the only complete solution will be a synthetic manganese dioxide of requisite purity. Batteries deteriorate too rapidly when impure material is used. The purpose of the appropriation is to set up laboratory equipment for testing ores brought in by exploration crews and for conducting research on the preparation of a superior synthetic product.

Chromium, electrolytic and sponge

Objective.—To enlarge and continue to operate the pilot electrolytic chromium plant at Boulder City, Nev., and to erect and operate a sponge chromium plant based on past development and to demonstrate the value and utility of the products.

Significance of the problem.—Both electrolytic chromium and sponge chromium are forms of highly pure metal suitable for use in alloys of a wide variety. The electrolytic material can be used for the preparation of molten alloys and the sponge chromium (a powdery form), used for the powder metallurgy sintering technique of making alloys. The silicothermic and aluminothermic chromium available contain elements other than chromium and cannot meet their widest usefulness on that account. The two forms can be combined with the desired metals with no fear of contamination, a highly desirable end during war production. The Boulder City pilot plant for electrolytic chromium is small and does not build up a stock of finished metal fast enough to supply the experimenters, governmental and industrial, who believe that they can make better products with it. This is a very important point as shown by the experience with the pilot plant on electrolytic manganese where such a supply of finished product accelerated commercial producton by several years, and thus put an infant industry on its feet. In addition, better alloys are anticipated with more efficient use of chromium. The sponge chromium project is one that passed through the "gram" scale in the laboratory and the test plant or "pound" scale, and is now ready for the pilot plant. Uses in guided missiles are anticipated and many other alloys that can be formed from powdered chromium have similar application for military use. Electrolytic chromium is ideal for stock piling and if properly packaged, sponge chromium can also be stored.

Nickel-bearing ores of Pacific Northwest

Objective.—To test in large smelting furnaces the direct smelting of several deposits of nickel-iron ores containing small amounts of chromium, developed in Washington and Oregon on a sufficient tonnage basis to justify an electric smelting operation.

Significance of the problem.—Two deposits of iron-nickel ore with small amounts of chromium were developed during the war in Washington, and a much larger one at Riddle, Oreg., with prospects of others in the latter district. A small appropriation has been available for the past 2 years for preliminary attempts at smelting in a rather small shallow electric furnace. It is found that a much deeper smelting zone promises better results and funds are needed to acquire an additional furnace to carry forward this promising project. In addition, it is thought that the passage of the material through a sponge iron furnace with magnetic removal of the iron-nickel alloy will give a concentrate that can be more economically melted electrically in the shallow furnace, and which will not require the use of coke, a costly article in the Northwest. This should add to the domestic nickel supply and if not commercial in normal times, will at least be applicable in time of emergency.

Cobalt-nickel-complex ore of Missouri

Objective.—To supply a solution to the problem of recovery of all valuable metals from a large pyritic complex ore body containing cobalt, nickel, copper, lead, zinc, silver, and other metal, which has gone through two wars without adequate metallurgical treatment.

Significance of the problem.—In southeastern Missouri, is a considerable zone containing ores with an attractive gross value if the various elements were separated from each other. The three major values are in cobalt, nickel, and copper, but there are also important values in lead, zinc, and silver that cannot be ignored. In the First World War, they were worked for nickel and cobalt mainly. Repeated attempts have been made to apply the usual metallurgy to them, with disappointing financial results. During the second World War, they were again worked for recovery of only a portion of their metal values and there were few smelters where even this fraction could be credited. The tonnage and gross value is enough to justify a more complex metallurgy which should be worked out in a time when hurried decisions on methods of extraction and marketing need not be made. The "know-how" should be developed now and there should be a reasonable profit now. A number of attractive methods of separation have been worked out on small laboratory scale; the next step is to sift out these methods on the test-plant scale and then try the best one on pilot plant scale. Until this has been done, the Fredericktown area is of dubious value and not ready for exploration when another emergency arises.

Iron and steel metallurgy

Objective.—To continue and complete the sponge iron and alloy projects partly completed during World War II by the Bureau of Mines.

Significance of the problem.—The war was well under way before appropriations were available for improved iron and steel metallurgy based on the low-grade and complex ores of "tomorrow." The war demands brought into sharp focus the dwindling supply of lush ore in the great Lake Superior iron-ore ranges. These better ores are expected to reach exhaustion within 20 years, but associated with them are very large tonnages of lower-grade ores of all degrees of complexity that should yield to various concentrating processes. Some of them are known to be easily concentrated and some look almost hopeless. The value of an iron ore is low, so processes that are applied should have very low costs or they should add other economic benefits than mere concentration of iron content. Many of the ore deposits in other parts of the Nation are of the same character, notably the Birmingham, Ala., area and many of the West coast ores.

A significant advance was made in the various sponge iron processes during the war to the extent that control over the sulfur content of the sponge was attained, whereas it was usually lacking in prior sponge iron work and this had been the greatest deterrent. Results were obtained too late to be of value in the war and the processes are not yet completely proven on a pilot-plant scale. The rotary-kiln pilot plant at Laramie, Wyo., was delayed in erection to the point that only short shake-down runs have been made showing what corrections were necessary. The decrease in available funds has forced cessation of this project. Sponge iron made by brickyard-furnace methods from high-grade ore of North Carolina not only proved to be equivalent to Swedish grade sponge iron, but there is an opportunity to supply a much greater annual tonnage of it. The ceramic saggers used in wartime, should be displaced by heat-resisting metal alloy saggers and only a start had been made when funds were withdrawn. This last step in the pilot-plant research should

require only about 1 year. The vertical shaft furnace using gas reduction of iron ore to sponge at the Minneapolis, Minn., experiment station is the last word in gas reduction and the result of accumulated knowledge. The Minneapolis effort has also involved improvement in magnetic roasting methods of concentration, and in the agglomeration of the fine sizes of ore into water-bound balls, and provided a simple and easy way of utilizing gravity and flotation concentrates. The Minneapolis operation, which is adjacent to the huge low-grade taconites, should be conducted on an even larger scale than has been done during the past year.

The electric melting furnace at Redding, Calif., was erected to melt the various grades of sponge iron with suitable alloying elements to make low-carbon iron and steel alloys of higher purity than is readily obtained by present methods. This is based on the fact that sponge iron is a metallized solid iron ore, with practically none of the usual impurities found in steel. These impurities tend to remain in slag when the sponge is melted.

Lastly, in the Birmingham area the Bureau has worked out, on a small scale, five different flotation processes, each applicable to a certain class of iron ore, which have not yet had the benefit of pilot-plant proof. At the same place, a study of gravity methods for concentrating the coarser sizes of ore have resulted in the invention of a new, simple, and efficient classifier with open bottom that indicates possibilities of decreasing part of the present losses of iron mineral and of increasing the grade of the concentrate. Summarized, there are five pieces of unfinished business in iron and steel metallurgy that are fundamental to the pattern that will soon face the whole steel industry:

(*a*) Rotary-kiln sponge iron (low sulfur).
(*b*) Brickyard-kiln sponge iron (Swedish grade).
(*c*) Vertical shaft gas reduced sponge iron.
(*d*) Electrical melting and alloying of sponge iron.
(*e*) Concentration of finely crystalline iron ores.

Titanium extraction and uses

Objective.—To accelerate the development of titanium metal and improve extraction of its oxide pigment from low-grade titanium ores.

Significance of the problem.—High-grade ores of titanium are not too plentiful. Lower-grade ores contain an almost unused metal that is the fourth most plentiful of those that might be used for structural purposes (the three more plentiful are aluminum, iron, and magnesium). The unique properties of titanium are its medium light weight, its strength, and its high resistance to corrosive influences, promising to rival stainless steel. If used in aircraft construction, it takes only half the weight of titanium to provide as much strength as magnesium. If substituted for stainless steel, it relieves the demand for chromium and nickel, important constituents of stainless steel. Titanium oxide is one of the finest white pigments available and replaces white lead and zinc white to a great extent. Titanium and its oxide are, therefore, substitutes or superior replacements for other strategic or critical minerals.

Two small pilot plants are in operation by the Bureau, one at Boulder City, Nev., extracting the metal from its ore, the other at Salt Lake City, fabricating the crude metal into finished shapes producing titanium alloys. The Bureau of Mines is the sole producer of ductile titanium metal, and the demand is greater than the output of these plants; most of this demand comes from the research departments of the armed forces. It is highly essential that the capacity of these plants should be doubled or trebled instead of having their operating funds heavily cut, as is now the case. This development is felt to be by far the most important present investigation of the Metallurgical Branch.

Subsidiary to this are two steps in the concentration of titanium from its ores requiring investigation, one being the use of a pilot plant for extracting both pigment-grade and metallurgical-grade titanium oxide from low-grade ores by the usual acid processes, and the other being a matte smelting method of extraction to prepare the raw material for final conversion to metal. This plentiful element which has been almost forgotten for so long will be immediately useful and can replace strategic materials and greatly improve industrial efficiency.

Zirconium extraction and uses

Objective.—To enlarge the scale of operations for production of metallic zirconium, its fabrication into shapes like rod, sheet, and wire, and building up a supply for Government and industrial laboratories to test out its uses.

Significance of the problem.—This metal is in a higher bracket of physical properties, particularly with respect to its resistance to corrosion, rivaling

tantalum and even platinum for many purposes. It, therefore, should be regarded as a substitute or replacement for a number of strategic metals that seem doomed always to be in short supply in the United States. The preliminary work on experiment station scale has been successfully carried through a 4-pound batch test plant, and parts of a 40-pound plant have been eked out from the present appropriation. It is proposed to erect a complete 100-pound unit for extractive metallurgy and with it a unit of corresponding capacity for converting zirconium metal powder into ductile shapes, suitable for fabrication into test articles in the pure or alloyed form. This permits accumulation of a stock for allotment to the laboratories of the armed forces, and other Government and industrial laboratories for testing out proposed uses. In this manner finished articles can be made and put in the hands of potential customers for the final use test. It is this step that creates a firm demand and assures success to enterprises interested in entering the zirconium metal business. Very favorable tests are underway for surgical uses because the material seems to be inert to body tissues and does not injure them in any known manner.

Vanadium, extraction and uses

Objective.—To carry out on pilot-plant scale two processes for the recovery, purification and fabrication of vanadium known to be present in a newly discovered domestic deposit large enough to make the Nation independent of foreign supply.

Significance of the problem.—The exploration for vanadium carried on during the last war exposed part of a very large formation in the phosphate beds of Idaho and Wyoming, which contains an attractive but marginal (economically) content of vanadium and too little phosphorus to be worked for phosphate alone. A process or processes that recover both elements and separate them from each other promises to be economic even in peacetime. The local demand for phosphate fertilizer is growing and an increased amount of phosphate extracted by acid processes can be sold. The Bureau of Mines has worked out a sulfuric acid process and a nitric acid process that can do this and the sulfuric acid process is ready for full-scale pilot planting. Several companies are also considering electric-furnace smelting of phosphorus in the western area, because pure phosphorus can be shipped to more distant markets. No provision for vanadium recovery is made in this proposal and it is thought that, by slight changes of practice, the vanadium can be collected in a byproduct (ferrophosphorus) in more concentrated form and subsequently extracted. This can be learned only by use of a fairly large furnace and it is proposed to erect such a furnace for the production and study of ferrophosphorus-vanadium separation. The vanadiferous bed in the area is only slightly below the upper reach bed of phosphate rock and can be mined with it. Both processes will have to be studied to make possible recovery of all vanadium that might otherwise be wasted. Here is an incomparable opportunity to build a vanadium industry based entirely on domestic resources.

Magnesium, nickel, chromium dunites

Objective.—To recover nickel and chromium as byproducts in the process of extracting magnesia or magnesium chloride from olivine dunites of the Appalachian and Northwest Cascade Mountains.

Significance of the problem.—During the war, both the Bureau of Mines and the Tennessee Valley Authority operated pilot plants on hydrochloric acid extraction of magnesium chemicals from the olivine dunites. This work was done in connection with the magnesium industry. The presence of small amounts of nickel (0.1 to 0.5 percent) and of chromium minerals (chromite, 0.5 to 3 percent) was noted, but no effort was made to recover them. Areas in the dunites are known where the nickel and chromium contents are 5 to 10 times as great. These metals would be byproducts in an enterprise for extracting magnesia or magnesium chloride, but while the pilot plant of the Bureau of Mines is still in existence, modifications of the process should be studied, with a view to working dunites higher in nickel and chromium and recovering these strategic metals, thus increasing economic value of such a process. If these processes are to be used in time of ememgency, new plants probably should be erected on the deposits that are richest in nickel and chromium. The dunites of the Cascade Range in Washington and Oregon are also known to carry these elements and should be included in the study, though the plant is located at Norris, Tenn. Only a modest sum would be required to do the job as most of the necessary plant is in existence, and only minor changes and additions would be required. This project if suc-

cessful would increase substantially our domestic reserves of recoverable nickel and chromium.

Alumina, abrasive, from low-grade bauxite

Objective.—To operate the bauxite pilot plant at Bauxite, Ark., for 1 year to produce abrasive-grade as well as metallurgical-grade bauxite.

Significance of the problem.—Exploration of the bauxite fields of Arkansas during the war revealed only relatively low tonnages of high-grade bauxite, but much low-grade material. The field is divided between two counties and the bauxites of one field are low in iron and titanium, while those in the other field are higher in these elements. The bauxite mill has been operated on 10 stock piles representing the variations in the low-iron bauxite area. Cutting of appropriations has made it impossible to complete the job required on the high-iron bauxites, which are much more complex. Also, it is to be noted that most of the metallurgical-grade bauxite in recent years has been imported from the north coast of South America, where the white bauxites are more plentiful. The South American material does not contain as much titanium dioxide as the Arkansas fields and this impurity is desirable in making alumina abrasives. Therefore, the Arkansas mines were largely reserved before the war to supply the electric furnaces of the abrasive industry. It is proposed to complete the operation of the pilot plant with the objective of making metallurgical-grade bauxite, and then operate it for the remainder of the time available with the objective of making abrasive-grade bauxite concentrate, and thus further extending the reserves of available bauxite for this purpose.

Kyanite-sillimanite refractories

Objective.—To make enough "Navy" brick from domestic raw materials for a complete test on the furnaces of a destroyer, as a replacement for imported Indian kyanite now largely used for this purpose.

Significance of the problem.—Indian kyanite is a peculiar variety of the mineral that gives strong boiler-furnace brick with long life not equaled by the usual refractory brick that can be made from the traditional domestic materials. During the defense and war years, research was conducted on a small scale at the Norris, Tenn., electrotechnical laboratory of the Bureau of Mines, and small batches of brick were made from mixtures of domestic kyanite, sillimanite, and topaz that met both the Navy and A. S. T. M. specifications when tested in the laboratory. The Navy would now like to have a supply of these brick for real service tests in the boiler of a destroyer. It will involve mining and milling the sillimanite needed in the mixture from deposits in Georgia and South Carolina, discovered by the exploration program during the war, acquiring the other materials by purchase and installing some additional brick-making and firing equipment to make the desired quantity. The equipment will also make possible research on further improvements of brick that will have long life at sea and obviate the necessity of frequent repairs. The cost of the item is relatively small and the findings may prove of great importance in naval operations. None of the commercial suppliers of refractories have been able to equal the product.

Talc, synthetic block or substitute

Objective.—To continue to develop a synthetic block talc or devise a substitute.

Significance of the problem.—Most talc in nature is in powdered form or in compressed blocks that are full of cracks. Pure talc in sound block form is rare, yet such talc is one of the most useful radio insulators, particularly for the large insulators needed at the sending stations. War exploration revealed a small amount of block talc of good grade in Montana and a larger amount of poor grade in California. The synthesis of block talc seems to be the safest course to follow. A certain amount of work has been done, but the objective has not yet been reached. The natural block talc, when fired to harden, gives a product of the same dimensions as the original block, and this is highly important. If a satisfactory synthetic or substitute can be devised, a stock pile of imported block talc need be very small.

Industrial diamond, substitute

Objective.—To devise a granular, hard, tough material of hardness approaching that of the diamond, for use in drilling and exploration.

Significance of the problem.—The diamond drill has been one of the favorite tools for exploring underground ore bodies. In recent years, it has also been found economical to substitute a diamond drill for the cutting of blast holes in mines, and this has brought about a shortage in the supply of industrial diamonds

and a rise in price. The grade of material used in the drilling has also deteriorated. In a recent test, tungsten carbide toughened with additions of titanium carbide and tantalum carbide was substituted for the diamond chips in a drill, and proved surprisingly satisfactory. This was a preliminary test, but offers considerable promise. Synthetic materials of a hardness very close to that of the diamond have been made, but thus far, have been too brittle. Research has resulted in the toughening of other abrasives, and should lead to methods of toughening hard carbides. The solution of the problem would render stock piles of industrial diamonds unnecessary or at least much smaller.

Thallium metal extraction and uses

Objective.—To develop means of extraction and purification of thallium metal and improve its uses.

Significance of the problem.—For security reasons, the exact military use of thallium will not be mentioned. It is a newly adopted metal that has had little previous use. An exploration has shown that considerable amounts of the metal are available in very low grade ores. The problem of extracting it does not appear difficult and it is thought that a relatively small appropriation will be sufficient to work out certain problems for its recovery, purification, and use.

Gallium extraction and use

Objective.—To devise processes of extractive metallurgy for recovery, purification, and use of the rare metal gallium, for a secret military use.

Significance of the problem.—Gallium is the only metal other than mercury that is liquid at low temperatures, but differs from the latter in having a high boiling point. Use of this fact can be made in certain military devices if a sufficient supply can be assured. The metallurgy of gallium must, therefore, be worked out as the small amounts available for purchase now are produced by noncommercial means and cost more than platinum. An exploration has revealed promising sources of very low grade material. The extractive metallurgy must now be worked out. A small fund is asked to study the sources of supply and how they can best be utilized.

Lightweight aggregate

Objective.—To study preparation of lightweight aggregate for structural and insulation purposes, both civilian and military.

Significance of the problem.—Certain minerals on heating expand and bloat considerably, thus giving a lightweight material with high heat- and sound-insulating qualities, and sometimes of considerable structural strength. Vermiculite is one of these, but loses strength when wetted and is not in plentiful supply. The common bloating clays are widespread, but have been crudely prepared. In the west, a volcanic lava called perlite will also expand on heating.

It is proposed to develop a recent discovery made in the small-scale laboratory that certain substances can be added to clays that act as baking powder when they are heated. It is possible to get bloated materials in which the pores are largely sealed, and, therefore, the granules do not absorb water. By the proper use of baking powder, the size of the pores, thickness of the cell walls and crushing strength of the expanded granules can probably be controlled, yielding valuable lightweight products. Further improvement is anticipated by the addition of fluxes to lower the melting point of a clay and save fuel.

Uses of such aggregates are numerous in both civilian and military fields. Lightweight concrete demands less reinforcing steel. Buildings and bridges can be more economically and safely constructed. In fortifications, a solid concrete is profoundly shattered when struck by shells or bombs. A lightweight concrete contains pores that absorb shocks without profound cracking and shattering, thus confining damage to a much smaller area. Lightweight concrete can be considered for arched roofs over airdromes.

The baking-powder technique of the Bureau of Mines should make it possible to use nearly any type of clay, since the small addition of baking powder permits control of bloat. Areas containing no solid sand or gravel always have clay or soil, which can be converted into bloated aggregate suitable for concrete construction. Aggregates have never entered Government stock piles, but this investigation offers a means of utilizing many types of clay as sources of usable aggregate.

Service, metallurgical testing of exploration samples

Objective.—To provide testing facilities for samples of mineral materials collected by exploration crews of Bureau of Mines and Geological Survey.

Significance of the problem.—The work of the Metallurgical Branch of the Bureau of Mines is essential in examining and testing the samples collected by field-exploration crews. Both the Geological Survey and Bureau of Mines Mining Branch are in the field examining potential mineral deposits; wherever the ore is low grade or complex, testing is required to determine its amenability to milling or other extractive metallurgical processes. If proven to be amenable to the usual processes, the material becomes a stock pile in the ground that requires no further investigation, except as to volume and tonnage. The Mining Branch estimate includes funds for analytical chemical analysis, but not for metallurgical testing.

STRATEGIC AND CRITICAL MINERALS PROGRAM—BUREAU OF MINES

Mining Branch, May 1947

Résumé

The activities conducted under this program were initiated in accordance with the mandate of the Strategic Materials Act of 1939 and are continued by the Stock Piling Act of 1946. The broad objective is to improve the Nation's internal position in respect to reserves of those minerals "* * * essential to the common defense or the industrial needs of the United States, and the quantities or grades of which are inadequate from known domestic sources * * *."

While only seven metals were considered to be strategic in 1939 when the program started, almost all metals and minerals were in short supply during the war and the program was consequently greatly expanded. During the seven fiscal years from July 1939 until July 1946 more than 9,000 engineering examinations were made, about 900 development projects were conducted, many miles of trenches were dug, hundreds of thousands of feet of holes were drilled, tens of thousands of samples were analyzed, and hundreds of beneficiation tests were performed. As a result of this work, millions of tons of ore of valuable metals and minerals were developed. A considerable fraction of this ore was mined by the industry and used in the war; the remainder is known to be available when or if it is needed.

In spite of all this work, the Army-Navy Munitions Board now lists 50 metals and minerals as strategic. If the mandate of section 7 (a) of the Stock-Piling Act is to be carried out effectively, and if the Nation is to be in any sense secure during an emergency, it is the considered judgment of the Bureau of Mines that the efforts in this program must now be redoubled. In order to secure optimum results, funds appropriated for this purpose should be on the order of $5,000,000 annually.

Statement, Strategic and Critical Minerals Program, Bureau of Mines, Mining Branch, May 1947

Authority

The activities conducted by the Bureau of Mines under its strategic and critical minerals program are sufficiently authorized by its organic act (36 Stat. 370, Public, 179, May 16, 1910 (revised by 37 Stat. 681, Public, 386, February 25, 1913). More specific legislative authorization is provided, however, by the Strategic Materials Act of 1939 (Public, 117, 76th Cong., June 7, 1939) and by the Stock-Piling Act of 1946 (Public, 520, 79th Cong., 1946) sections 7 (a) of the 1939 act and the 1946 act both make provision that:

"The Secretary of the Interior, through the Director of the Bureau of Mines and the Director of the Geological Survey, is hereby authorized and directed to make scientific, technologic, and economic investigations concerning the extent and mode of occurrence, the development, mining, preparation, treatment, and utilization of ores and other mineral substances found in the United States or its Territories and insular possessions, which are essential to the common defense or the industrial needs of the United States, and the quantities or grades of which are inadequate from known domestic sources, in order to determine and develop domestic sources of supply, to devise new methods for the treatment and utilization of lower-grade reserves, and to develop substitutes for such essential ores and mineral products; on public lands and on privately owned lands, with the consent of the owner, to explore and demonstrate the extent and quality of deposits of such minerals, including core drilling, trenching, test-pitting, shaft sinking, drifting, cross-cutting, sampling, and metallurgical investigations and tests as may be necessary to determine the extent

and quality of such deposits, the most suitable methods of mining and beneficiating them, and the cost at which the minerals or metals may be produced."

The several appropriation acts whereby funds have been provided for conducting the program have given certain specific authorizations and in some cases have imposed limitations as to type of activity to be conducted or commodities to be investigated. The current appropriation, entitled "Investigation and Development of Domestic Mineral Deposits, Except Fuels" is limited in commodities only by the exclusion of fuels. Its specific provisions are as follows:

"To investigate, develop, and experimentally mine, on public lands, and with the consent of the owner on private lands, deposits of minerals in the United States and its possessions, including surface and subsurface investigations, laboratory tests, the construction, maintenance, and repair of necessary camp buildings, mining structures and appurtenances, the lease of lands or buildings * * * provided that the Director of the Bureau of Mines, for the purposes of this appropriation, is authorized to accept lands, buildings, equipment, and other contributions from public or private sources and to prosecute projects in cooperation with other agencies, Federal, State, or private."

Objective

The broad objective of the strategic and critical minerals program of the Bureau of Mines is to improve the Nation's internal position in respect to those minerals "* * * essential to the common defense or the industrial needs of the United States, and the quantities or grades of which are inadequate from known domestic sources * * *."

The program begun in 1939 under the Strategic Materials Act was at first conducted on the principle that investigations would be limited to deposits of seven usually imported metals listed by the Army-Navy Munitions Board as certain to be in short supply in case of national emergency. The problem was to find domestic sources that conceivably could produce the metals when or if they were needed badly enough. The ideal sort of deposit, under this concept, was one containing enough total metal to contribute a sizable fraction of the country's needs, but just low enough in grade to be unprofitable in ordinary times. "Underground stock piles" were visualized, all sampled and blocked out, waiting to be mined if an emergency should arise.

During the war, the program was expanded in size and in scope to include almost all metals and minerals because most of them became critical. The long-range objective of establishing "underground stock piles" that would be available when or if needed was superseded by the immediate one of helping to step up production. Development work was done shortly ahead of production in some cases at that time because of the acute shortages.

Now that the war is over, the program is returning to the prewar objective of establishing "underground stock piles." The scope of the program is considerably broader, however, in the number of commodities being studied and the completeness of the investigations than it was in 1939. There are now approximately 50 metals and minerals on the strategic and critical list of the Army-Navy Munitions Board instead of 7. During the war, it was demonstrated that in the case of certain scarce minerals production does not always result in times of stress even though the location of low-grade deposits is known and cost is no object. Dangerous delays, and sometimes insurmountable obstacles, are encountered if a proper groundwork has not been laid. In the case of low-grade mineral deposits that may be needed in time of emergency, it is essential to have methods of mining and treating the ore worked out well in advance. The lag between the time of preliminary investigation of a deposit and the beginning of actual production, even in the case of immediately commercial deposits, often runs into years. This lag cannot be sufficiently telescoped in time of emergency to make up for lack of painstaking development work.

Because the broad objective of the program is to improve the country's internal position regarding strategic and critical minerals, it is not considered to be the function of the Bureau of Mines to perform development work that would otherwise be done by private enterprise. Projects are not conducted, as a rule, upon deposits that reasonably would be expected to become commercial in the immediate future. It is difficult to determine in advance of development that a deposit is sufficiently good to be of interest from the long-range, national viewpoint and still not quite good enough to become commercial in the near future. Consequently, a few of the deposits investigated will continue to come into production even though that is not the primary objective of the program.

Procedure

In order to accomplish the desired objective, a definite procedure is followed in investigating the deposits under consideration. The several steps are:

(1) Engineering examinations on which to base estimates of the possibilities of the deposits and the most economical methods of developing them. Many of the examinations, of course, result in the conclusion that the deposits are not of sufficient size or grade to be of interest from the national viewpoint expressed in the Stock Piling Act. A priority list of proposed projects is periodically revised in the light of the additional information continually being made available by preliminary examinations.

(2) Probing and sampling by means of trenching, drilling, or underground openings of those deposits that seem to warrant it from the national viewpoint. The greater share of the funds available is expended in this phase of the program.

(3) Analysis of samples obtained: The samples are analyzed chemically or by other means in order to determine their content of valuable metal or mineral and the percentage of deleterious constituents.

(4) Beneficiation tests on samples of those ores that present treatment problems. Because the minerals under investigation are, by definition, found in inadequate quantities or grades in domestic deposits, the valuable material contained in many of the deposits is difficult to recover. Tests are first made by standard methods. If these are unsuccessful, new combinations of methods are tried and in some cases new methods are devised.

(5) Calculation of tonnage and average grade. Based on the geometric spacing of the samples obtained from excavations and probings and reasonable projections of the pattern thus obtained, the tonnage of material that probably could be mined is calculated. Weighted averages compiled from the chemical analyses of the samples are applied to the calculated tonnage to indicate the percentage of valuable metal or mineral.

(6) Estimate of production costs. When the size, shape, attitude, and depth of the minable portion of a deposit have been determined, plus certain factors such as the probable strength of the wall rock, an estimate can be made of the probable cost of mining. Likewise, an estimate can be made of the probable cost of extracting the valuable metal or mineral from the ore when a feasible method of beneficiation has been determined.

(7) Publication of results. As soon as practicable after the completion of the investigation of a deposit, a report of investigations is issued giving the basic factual data as developed by the project. This report includes maps and graphs showing the distribution of drill holes, trenches, and other openings and indicating the places from which samples were taken. The chemical analyses of the samples are listed in relation to the sample locations and results of beneficiation tests are described. The calculations of tonnage and average grade and the estimates of costs of production are not published because they are necessarily based upon assumptions in regard to constantly changing economic factors.

Commodities investigated

The seven metals on the original list for investigation in 1939 were:

Antimony	Mercury	Tungsten
Chromium	Nickel	
Manganese	Tin	

During the war, when the objective was immediate production in almost all metals and minerals, projects were conducted upon a much longer list of commodities:

Alunite	Copper	Mica
Antimony	Corundum	Molybdenum
Asbestos	Diamonds (industrial)	Nickel
Barite	Fluorspar	Quartz crystals
Bauxite	Graphite (flake)	Sulfur
Beryl	Iron ore	Talc
Bismuth	Lead	Tantalum
Calcite	Lithium	Tin
Chromite	Manganese	Tungsten
Clay (high alumina)	Magnesium	Vanadium
Cobalt	Mercury	Zinc

The current list of strategic and critical materials was published by the Army-Navy Munitions Board in January 1945. In presenting the list, the Board submits the following definition: "Strategic and critical materials are those materials required for essential uses in a war emergency, the procurement of which in adequate quantities, quality, and time is sufficiently uncertain for any reason to require prior provision for the supply thereof."

The list is divided into three groups on the following basis:

A. "* * * those strategic and critical materials for which stock piling is deemed the only satisfactory means of insuring an adequate supply for a future emergency."

B. "* * * additional strategic and critical materials, the stock piling of which is practicable. The Army and Navy Munitions Board recommends their acquisition only to the extent they may be made available for transfer from Government agencies because adequacy of supply can be insured either by stimulation of existing North American production or by partial or complete use of available substitutes."

C. "* * * Those strategic and critical materials which are not now recommended for permanent stock piling because in each case difficulties of storage are sufficient to outweigh the advantages to be gained by this means of insuring adequate future supply."

The metals and minerals included in these three groups are as follows:

A

Antimony
Asbestos
Bauxite
Beryl
Bismuth
Cadmium
Celestite
Chromite
Cobalt
Columbite
Copper
Corundum
Diamonds, industrial
Graphite:
  Amorphous lump
  Flake
Iodine
Kyanite, Indian
Lead
Manganese ore:
  Battery grade
  Metallurgical grade
Mercury
Mica: Muscovite block, and film, good, stained, and better
Monazite
Nickel
Platinum group metals:
  Iridium
  Platinum
Quartz crystals
Rutile
Sapphire and ruby
Talc, steatite, block or lava
Tantalite
Tin
Tungsten
Vanadium
Zinc
Zirconium ores:
  Baddeleyte
  Zircon

B

Aluminum
Barite
Chalk, English
Chromite, chemical grade
Cryolite, natural
Emery
Fluorspar:
  Acid grade
  Metallurgical grade
Graphite, crystalline fines
Magnesium
Mica:
  Muscovite block, stained or lower
  Phlogopite block
Molybdenum
Platinum group metals:
  Osmium
  Palladium
  Rhodium
  Tuthenium
Selenium
Talc, steatite, ground

C

Asbestos, Canadian chrysotile
Iron ore
Petroleum and petroleum products
Radium

The list of metals and minerals to be investigated by the Bureau of Mines, in general, is based on the strategic and critical list of the Army-Navy Munitions Board. The two lists are not entirely coincident, however, because somewhat

different considerations govern the selection of items. A few of the minerals on the Army-Navy list are known to occur in such meager quantities in the United States that it seems wasteful to spend additional funds trying to develop material that will not be used in the foreseeable future. In several cases there are known deposits of substantial size in the country that could be used in an emergency, but that are not now being mined. Such minerals probably will not be investigated by the Bureau unless some new factor enters into the situation. In other cases, minerals not on the Army-Navy list may be investigated by the Bureau with the idea of developing substitutes or replacements for strategic items.

Funds

Although the appropriation title under which the program is currently conducted, "Investigation and development of domestic mineral deposits, except fuels," is new in fiscal year 1947, the present program was initiated in 1939. Funds appropriated for this activity reached a wartime peak of more than eight million dollars in fiscal year 1944. The appropriation for the current fiscal year is approximately 20 percent of the peak figure and is comparable to the appropriation made for the last year of peace prior to the war.

A tabulation showing the various appropriations made for this program, by fiscal years, follows:

Progress

In considering how to present the progress made in the program most clearly in a brief statement, a number of possibilities suggest themselves: The number of engineering examinations could be listed; it is more than 9,000. The number of projects could be tabulated, about 900. The miles of trenches dug, the hundreds of thousands of feet of holes drilled, the tens of thousands of samples analyzed, the hundreds of beneficiation tests performed, and the publications issued could all be tabulated.

The most definitive expression of progress, however, is given by a tabulation of the tonnages and grades of the several commodities developed by the work. Such a tabulation follows:

Investigation and development of domestic mineral deposits, except fuels

Name of appropriation	1940	1941	1942	1943	1944	1945	1946	1947	1948 [1]
Working fund:									
Appropriation		$500,000							
Personnel		36							
Investigation of bauxite and alunite ores and aluminum clay deposits:									
Appropriation			$415,000	$998,500	$1,860,000	$1,860,000	$500,000	(4)	
Personnel [2]			16	64	108	100	41		
Investigation of deposits of critical and essential minerals in the United States and its possessions:									
Appropriation				$2,818,765	$3,900,000	$2,900,000	$2,100,000	(4)	
Personnel				325	443	347	235		
Investigation of domestic sources of mineral supply:									
Appropriation	$350,000	$625,000	$950,000	(3)					
Personnel	41	61	105						
Investigation of raw material resources for steel production (50 percent):									
Appropriation			$175,000	$174,662	$1,200,000	$1,625,000	$625,000	(4)	
Personnel			8	13	79	164	99		
Drainage tunnel, Leadville, Colo.:									
Appropriation					$1,400,000				
Personnel					6	8	5		
Investigation and development of domestic mineral deposits, except fuels:									
Appropriation								$1,700,000	$1,600,000
Personnel								223	223
Grand total:									
Appropriations	$350,000	$1,125,000	$1,540,000	$3,991,927	$8,360,000	$6,260,000	$3,225,000	$1,700,000	$1,600,000
Personnel	41	97	129	402	630	615	380	223	223

1 Estimated.
2 Permanent.
3 Combined with critical and essential minerals.
4 Combined with investigation of domestic minerals.

Tabular summary of tonnages developed by Bureau of Mines projects

[Fiscal years 1940–46, inclusive]

Commodity	Number of deposits	Tonnage of crude material	Grade	Contained metal or useful mineral	Remarks
Alunite	9	11,000,000	21.5 percent Al_2O_3		Possible source of alumina.
		7,000,000	14.0 percent Al_2O_3		
Antimony	5	29,000	10.0 percent Sb		
		3,200,000	1.7 percent Sb		
Asbestos	4		No. 1 fiber	3 T	
			No. 2 fiber	150 T	
			No. 3 fiber	400 T	
			No. 4 fiber	14,000 T	
Barite	2	11,000	45 percent Ba		
Bauxite	250	21,500,000	A		Aluminum ore.
		9,000,000	B		
		10,500,000	C		
		33,000,000	D		
Bismuth	1	10,000	0.68 Bi		
			0.76 Cu		
Optical calcite	3			Several hundred pounds	
Chromite	25	5,600,000	22.4 percent Cr_2O_3		
		3,700,000	9.3 percent Cr_2O_3		
Alumina clay	21	382,000,000	26.7 percent Al_2O_3		
Cobalt	1	4,400,000	0.54 percent Co		
			1.40 percent Cu		
Copper	46	2,219,000	2.55 percent Cu		
		39,000,000	0.88 percent Cu		
Corundum	7	6,000	Fair		
Industrial diamonds	1			Small amount	
Fluorspar	25	730,000	51 percent CaF_2		
Flake graphite	5	26,000,000	3 percent C		
Iron	67	530,000,000	40.3 percent Fe		
Lead-zinc	66	14,430,000	4.3 percent Zn		Much of crude tonnage is duplicated.
		7,490,000	3.0 percent Pb		
Manganese	56	21,000,000	12.8 percent Mn		Exclusive of large submarginal deposit in South Dakota.
Magnesium	2			1,600,000 T. carnallite	
				265,000 T. sylvite	
		144,000	37.5 percent MgO		
Mercury	40	1,800,000	5 pound Hg per T		
Molybdenum	4	3,000,000	0.23 percent MoS_2		
		550,000	0.54 percent MoS_2		
Nickel	10	27,000,000	0.50 percent Ni		

Pegmatite minerals	200	(1)			
Quartz crystals	2			None	
Sulfur	1	33, 600	23.6 percent S		
Talc	1			Several hundred tons of block talc.	
Tin	10	310, 000	1.1 percent Sn		Lode deposits.
			0.24 percent WO_3		
		4, 000, 000	0.3 percent Sn		Low-grade lodes.
		[2] 2, 200, 000	½ pound Sn per cubic yard		Placer deposits.
Tungsten	27	4, 200, 000	0.69 percent WO_3		
Vanadium	10	50, 000	2.3 percent V_2O_5		
		45, 000, 000	0.9 percent V_2O_5		

[1] Approximately 1,000,000 tons containing usable quantities of mica, beryl, lithium, and tantalum.
[2] Cubic yards.

Future program

As mentioned earlier, the Bureau of Mines is directed by Public Law 520 to make certain investigations and to do certain development work on deposits of strategic and critical minerals. The scale on which this work can be done depends upon the size of appropriations made by Congress.

If appropriations are limited, very little progress can be made. This fact was recognized before the end of the first year of operation of the program, and, as shown on the attached table of appropriations, the second year's funds were more than three times as large as the first. During the war, of course, the program was greatly accelerated, but has since been reduced. The budget estimate for fiscal year 1948 is comparable in size to the last prewar fiscal year, starting in July 1941. This modest request was made in line with the President's economy order. The House bill cut this amount in half. Considering the increase in salaries and in the prices of supplies and equipment, the amount provided by the House bill will buy very little more than was possible in the first small year of the program. As there are now 50 minerals on the strategic list compared to 7 in 1940, the progress that can be made with such an amount is small, indeed, compared to the size of the task imposed by the Stock-Piling Act. The optimum size of the program would be one that could make reasonable progress toward inventorying the Nation's reserves of strategic and critical minerals, in, say, 10 years. It is recognized that such an inventory can never be completed, that it is a continuing job, but if the provisions of section 7 (a) of Public Law 520 are to be carried out effectively, the rate of progress must be more rapid than it was prior to the war. If we are to be prepared for a national emergency, we must stockpile quantities of these metals and minerals to tide us over the period of gearing our industry to emergency levels. If we are to be able to speed up our production of metals and minerals to emergency levels, we must have, in addition to stock piles, an adequate supply of known domestic deposits of every strategic mineral it is possible to find. If there are none to find in some commodities, we must know that in advance so that additional stock piles or substitutions may be provided.

The inadequacy of our known domestic resources of certain commodities is such that shortages are felt in our peacetime economy now that the war has been over almost 2 years. Congress recently has taken action to remove the tariff on copper in order to bring in sufficient peacetime supply, but we must look to our own resources if we are to be in any sense secure.

One of the most critical shortages at present is in lead, in spite of a comparatively high price. Lead, of course, is on the list of the Army-Navy Munitions Board for stock piling. But how are we to accumulate a stock pile when we cannot obtain sufficient lead for our current demands? There is no other way but to develop our own domestic deposits.

In order to make the greatest progress consistent with efficiency toward accomplishing the task required by section 7 (a) of the Stock-Piling Act, appropriations considerably larger than now contemplated are needed, although somewhat less than the wartime peak. The Mining Branch of the Bureau of Mines has operated its strategic-minerals program on every scale from $350,000 (fiscal year 1940) to $8,360,000 (fiscal year 1944). It is the considered judgment of this group that the optimum results will be obtained at the rate of approximately $5,000,000 per year.

Statement for Special National Resources Economic Subcommittee of the Senate Committee on Public Lands, Economic and Statistics Branch

SUMMARY STATEMENT

The Economics and Statistics Branch of the Bureau of Mines is the principal fact-finding agency of the Government in the field of minerals. Its basic statistical and economic services deal with raw materials that are essential to the peacetime and wartime industrial activity of the United States. Consequently the Branch program was quickly and easily converted to war needs. The Branch played a leading part in the early phases of the defense program. Because of its experienced staff and detailed knowledge of world minerals it was able to point out promptly the problems ahead and suggest lines of action that should be taken to meet them. As the defense program expanded the need for mineral data soon exceeded the facilities of the Branch. Most of the expansion in fact finding took place in the war agencies, but the Branch supplies many of the basic statistics, which were needed in planning and administering the war program. Besides these statistical services to the war agencies the commodity specialists of the

Branch served in an advisory capacity to many wartime officials and its data files were used extensively throughout the war by all war agencies.

At the close of the war, activities were readjusted to meet the needs of reconversion and permanent postwar operations. This necessitated a moderate expansion of the prewar program which war experience proved was inadequate for the peacetime needs of the Government in connection with national defense planning and other current activities. The demand for special information required for stock-pile planning and procurement under Public Law 520, Seventy-ninth Congress, necessitates a further increase in the Bureau's work in economics and statistics.

(a) and (b). Activities conducted during the national defense and war periods and the results accomplished.

The Economics and Statistics Branch has long been the principal fact-finding agency and the principal repository of economic information in the field of minerals. The war accelerated the demand for current comprehensive data on production, inventories, distribution, supply, and consumption of minerals and mineral commodities and necessitated marked expansion of the Bureau's services in collecting, processing, and analyzing statistics but called for no major disruption of established functions or organizational changes, only a slight shift in emphasis.

The normal peacetime activities of the Economics and Statistics Branch were of tremendous assistance in the complex problems of procurement of essential minerals, for it possessed a 60-year history of production, consumption, uses, and sources of supply. These records, comprised in the annual volumes, Mineral Resources of the United States, and later the Mineral Yearbook, furnished a wealth of basic statistical data that were drawn upon extensively by every agency concerned with procurement, restriction, and allocation of war materials of mineral origin. Extensive factual information is available also in the data files of the Branch which were established during the First World War and have been augmented continually during the ensuing years. These files were a constant source of information for scores of war agencies. They furnished the history of technologic and economic progress, growth or decline of the industries, nature of domestic and foreign deposits, innumerable descriptions of plants and equipment, data on uses, substitutions, world sources, price history, tests, specifications, analyses, and many other features of each mineral industry.

It may be added, however, that although the Bureau was ready and willing at all times to cooperate fully in conducting canvasses, it discouraged sending out questionnaires which, from our intimate knowledge of the industries, appeared to serve no useful purpose and which would place an unnecessary load on mineral producers and processors already overburdened with Government requests. These proposed questionable canvasses were the result of overenthusiasm or misguided judgment on the part of newly created war agencies that lacked a background of factual data on which the need for special inquiries should always be based. In several instances the information desired was already available. Quite a number of proposed canvasses that the Bureau of Mines regarded as unnecessary did not materialize, and time has proved that the judgment of its specialists was sound.

The Bureau's mineral economists made notable contributions to prewar attempts to fortify and man the mineral front. Consequently, its supervisory staff was thoroughly familiar with problems likely to be encountered under war conditions and was able to give sound advice and practical assistance to newcomers to Washington in the defense and war agencies in addition to directing the Bureau's own war program for supplying additional figures and for making special studies to supplement its usual periodic data on all mineral commodities. By making available its stores of information and through representation on committees and conferences, the Bureau was able to give warning of threatened bottlenecks in supply and to advise regarding available production and plant capacities, the need for expanding facilities, and the possibilities for conservation or substitution of some minerals for others.

EXPANSION OF STATISTICAL PROGRAM

Events in 1938 and 1939 in Europe left little doubt but that the United States eventually either would be involved in war or her industrial economy would be greatly disturbed by interruptions to the flow of strategic minerals from foreign sources. As a consequence the Government began close surveillance of our inventory position in raw materials. For this purpose it was apparent that the

annual statistics previously collected by the Bureau of Mines on most of the strategic and critical minerals were inadequate in detail and frequency. At the request of the Army and Navy Munitions Board collection of monthly statistics on the supply and use of chromite, manganese, mercury, mica, tungsten, tin, and aviation gasoline was instituted in September and October 1939. Because of shortage of funds it was necessary to recess virtually all economic research and concentrate the facilities of the branch on the expanded statistical job. However, demands for more and more data came rapidly as threats of mineral shortages became imminent because of the increasing size of the munitions program, submarine warfare, and other interruptions to imports. The Bureau of Mines was unable to meet all demands for statistical services because of its inability to obtain adequate funds. As a result several of the war agencies collected their own data. Thus the economy and efficiency of a centralized statistical unit for minerals could not be realized fully.

Despite the lack of sufficient funds the branch experienced a tremendous increase in its program. In 1938 it conducted 420 canvasses involving the auditing, interpretation, and compilation of approximately 170,000 reports from respondents. Later some 1,450 canvasses with 825,000 reports from respondents were being processed annually exclusive of those handled by the bituminous-coal group which was transferred to the Bureau of Mines in 1944. The number of reports prepared for public and confidential distribution increased from 461 to over 1,200 per year. These reports, which include Minerals Yearbook, the Government's annual report on the mineral industries, provided most of the essential facts on which the defense and war programs were planned and administered. The program was developed in close cooperation with all war agencies concerned with minerals in order to avoid duplication and to give maximum service to those responsible for the prosecution of the war on the industrial front. The statistical work likewise was coordinated with similar activities of business organizations for reasons of economy and to minimize the burden of questionnaires on industry.

NATIONAL DEFENSE ADVISORY COMMISSION

Because of its background in the national defense aspects of minerals and its extensive records of domestic and foreign mineral industries, the Economics and Statistics Branch was a readily available source of information needed in organizing the vast procurement and control measures required in the defense and war programs. It was natural, therefore, that C. K. Leith, who came to Washington to organize the mineral activity for E. R. Stettinius, Jr., in charge of industrial materials for the Advisory Commission to the Council of National Defense, should call on the Branch for assistance. This call was met in a spirit of full cooperation, and on June 3, 1940, 6 days after the appointment of the Advisory Commission, Dr. Leith established headquarters in the office of the Chief of Branch, where he remained for approximately a month building up staff and planning preliminary actions needed to secure the maximum amount of raw materials in the minimum of time. It should be recalled that the Commission was created hurriedly after the fall of France, which became imminent in May, gave a grim outlook to the international situation, and caused great concern over our own security. All facilities were placed at Dr. Leith's disposal and were used extensively. During the month he occupied quarters with the Bureau of Mines Government specialists and industrial experts were requested to come to Washington for consultation. Eleven industry meetings were held during this period out of which developed preliminary programs for procurement and use of antimony, chromite, manganese, mercury, tin, tungsten, asbestos, graphite, industrial diamonds, and mica. The agenda for these meetings were prepared largely by Bureau specialists.

Up to this time the Economics and Statistics Branch had pursued a course designed to make it the nucleus of the defense activities in minerals. Such a happy experience would have eliminated the unfortunate events of World War I, when the old-line agencies virtually were ignored and as a result experienced staff was not adequately used and precious records were dissipated and lost when the temporary agencies passed out of existence. In June 1940 it appeared as if the objective was in sight, but circumstances beyond the control of the Economics and Statistics Branch intervened and early in July the Advisory Commission staff moved to other quarters and the close collaboration already started gradually relaxed. Despite this disappointing turn of events the Branch continued to extend cooperation to the limit of its facilities. The major part of the statistical records for minerals in this war remains with the Bureau of Mines, and fortunately many important documents prepared by the war agencies at considerable

cost and containing data of great value for future activities will eventually come to the Bureau of Mines under a law recently enacted by Congress.

WAR ACTIVITIES

Although the work of the Economics and Statistics Branch continued to expand after Pearl Harbor, the declaration of war by the United States required no appreciable changes in functions or activities. The Branch was already on a war basis. The general outline of the Government's organization for administering the war program was established as was the division of labor between war and old-line agencies. The Branch had been given a major part of the responsibility for collecting the basic data on mineral raw materials. Statistics required directly for allocation of scarce materials and production control were collected largely by the mineral branches of the Office of Production Management (later called War Production Board). Each of these branches had its own statistical unit at first responsible to the Bureau of Research and Statistics of OPM, but later responsible only to the Director of the Branch. Likewise cost and price data required in administering war price controls were collected by the Office of Price Administration. The commodity specialists of the Economics and Statistics Branch continued to give professional assistance to war officials and the extensive data files and records of the organization were made available to authorized representatives of the war agencies.

The major load of increased statistical activity was in metals, virtually all of which were in short supply from 1941 to 1943. Rigid control measures adopted to make available supplies serve the most urgent needs required detailed and frequent statistical inquiries and analytical reports. Especially significant were the reporting services developed for iron and steel scrap and secondary nonferrous metals as the secondary metals industries were called upon for maximum production to supplement the full capacity output of metal mines. As industrial activity approached its peak and manpower problems arose, concern over the adequacy of the fuel supply developed. Statistics on bituminous coal, the most basic of all commodities, were improved to meet the needs of the Government and industry. This improved service is now part of the Bureau of Mines but the Bureau will be forced to discontinue the service if the action of the House of Representatives on appropriations for 1948 becomes law. The Bureau's fact-finding activities on anthracite, coke, and coke byproducts also were greatly expanded to meet the needs of the Solid Fuels Administration. Requests for data on the nonmetallic minerals and petroleum likewise required increased fact-finding and reporting activities. Data on employment and accident rates in the mineral industries also were supplied in substantial quantities to the war agencies seeking maximum and most efficient use of manpower. Information on foreign mineral installations and resources were given to military authorities planning bombing objectives and seeking answers to problems of mineral supply for the armed forces in distant places and problems of rehabilitation in occupied territory.

POSTWAR ADJUSTMENTS

After the war the statistical program was readjusted to meet reconversion and peacetime needs. Many canvasses were reduced in scope and frequency and some work formerly performed by the war agencies was transferred to the Bureau of Mines. In planning the postwar permanent program only those wartime improvements that experience proved were essential to peacetime needs were established on a permanent basis. Before the war there were no data available on such vital factors as normal industry stocks of manganese, chromite, tin, and other highly essential strategic minerals. There were no statistics on the use pattern of most of the strategic and critical minerals, and information on foreign sources of supply of those minerals that we must obtain abroad was grossly inadequate. Lack of reliable data on these important raw materials seriously handicaps industrial mobilization planning, stock-pile procurement, and the conduct of regular industry and Government activities relating to the mineral industries. Expanding production and consumption of minerals, increasing complexity of mineral utilization, growing dependence on foreign sources of supply, and the wider participation of the United States in international affairs in which minerals play an important part all present problems the solution of which requires full factual information. The Bureau's program in the field of mineral economics is designed to supply these needs.

(*c*) Activities required under the Strategic and Critical Materials Stock-Piling Act of 1946, Public Law 520, Seventy-ninth Congress.

Section 2 (a) of this law directs the Secretary of War, the Secretary of the Navy, and the Secretary of the Interior to determine, from time to time, the materials that are strategic and critical under the act, and the quantities and qualities of the materials to be stock-piled. The Economics and Statistics Branch of the Bureau of Mines is the principal source of the factual information needed to make these determinations for minerals. The Branch is also called upon to advise the Treasury Department, the procurement agency designated under the act, on market conditions and other factors pertinent to the acquisition and storage of minerals for the stock piles. To discharge these functions properly requires considerably more statistical and other factual information on domestic and foreign sources of supply, world trade, current relation of supply to demand, stocks on hand, the outlook for production and consumption under future peacetime and emergency conditions, costs, and prices than was available before the war. A larger staff of commodity specialists also is required to interpret the basic data in terms of national defense and procurement objectives.

ACTIVITIES OF THE BUREAU OF MINES IN CONNECTION WITH THE DEVELOPMENT, WINNING, PREPARATION, TREATMENT, AND UTILIZATION OF MINERAL FUELS ESSENTIAL TO THE COMMON DEFENSE OR INDUSTRIAL NEEDS OF THE UNITED STATES

May 20, 1947.

(*a*) Activities conducted during the national defense and war periods.
(*b*) Accomplishments under such activities.
(*c*) Activities that should be conducted to comply with the mandate in Public Law 520. (Strategic and Critical Materials Stock Piling Act of July 23, 1946.)

This statement covers the work in the following fields:

1. Coal.
2. Petroleum and natural gas, including helium.
3. Synthetic liquid fuels.

Mineral Fuels

During the national defense and war periods the military services and governmental agencies charged with minerals procurement called on the Bureau of Mines for technologic and scientific assistance in solving the problems which arose in the fields of coal and coke and petroleum and natural gas. Because of its peacetime research in conservation, production, and utilization of mineral fuels, the Bureau was in a position to provide needed information as well as men and laboratory facilities for additional research to surmount the obstacles that lay in the path of increased production for war.

Field investigations proved approximately 2,000,000,000 tons of coal for western steel plants and fuel-short areas, such as Alaska. The quality and quantity of coke produced were stepped up by field surveys and recommendations. Preparation studies up-graded coals to satisfy general and special-purpose demands and combustion research and a national fuel efficiency program resulted in savings of millions of tons of coal per year.

An outstanding record of helium production, marked by a production-rate increase of 1,150 percent, met all wartime demands for this invaluable gas. Through field engineering studies and surveying and laboratory research, a wealth of information on petroleum and natural-gas production problems, the composition of crude oils and base stocks for aviation gasoline and blending factors were contributed to the appropriate agencies.

Under Public Law 290 (78th Cong.), a 5-year program to investigate and demonstrate the feasibility of producing synthetic liquid fuels from coal, oil shale, etc., was inaugurated in 1944. Laboratory and developmental research was started immediately at Bruceton, Pa., Morgantown, W. Va., and Laramie, Wyo. An oil-shale demonstration plant started operations at Rifle, Colo., in May 1947. A demonstration for producing oil from coal is under construction at Louisiana, Mo.

To comply with the mandate to the Secretary of the Interior under Public Law 520, the Bureau of Mines proposes to:

(1) Investigate coal deposits in the field to provide adequate supplies of metallurgical coke and fuel;

(2) Study and evaluate methods of underground gasification of coal to increase our reserves through the utilization of submarginal coal beds;

(3) Continue basic studies and surveys of preparation methods, carbonization and coking properties, and combustion characteristics of domestic and Alaska coals;

(4) Make engineering estimates of the Nation's reserves of petroleum, natural gas, and helium and the rate of availability of these resources and conduct research of increased recovery;

(5) Evaluate the composition and characteristics of domestic and foreign crude oils; and

(6) Continue the synthetic liquid fuels program, develop the most improved methods of recovering and refining oil from oil shale and producing oil from coal, and demonstrate these methods on a scale large enough to develop cost data and provide engineering information necessary for commercial plant construction.

Coal

War activities included (*a*) the stepping up of Bureau of Mines service on coal-mining methods, blending at the mine, strip-mining procedures, mining equipment; exploration for coal of metallurgical grade for steel production, in the West and other fuel-short and strategic areas of Alaska and Washington; on coal preparation, inspection, sampling, analyses, testing; through its survey of coking properties of American coals and its work on making western subbituminous coal and lignite utilizable in war matériel production and through its studies of combustion to reduce boiler shut-downs with fuels in wartime uses; (*b*) creation of Solid Fuels Utilization Unit to provide basic data for allocations of supply, and technical and engineering assistance in use of such solid fuels; and (*c*) creation of facilities for conducting survey of coke-production methods to improve quality and quantity of that all-essential basic material.

The accomplishments: (*a*) Coal-mining activities resulted in increased production of coal through instruction in strip and other mechanizations, (*b*) quality of tens of thousands of tons of coal for wartime installations was insured, (*c*) exploration activities proved up 1,900,000,000 tons of new coal, (*d*) coal-preparation activities aided generally in providing low ash and sulfur contents in coal supplies, (*e*) basic data for substitution of fuel sources by allocating agencies, and (*f*) increased quantity and quality of both general and emergency coke production from accumulated basic knowledge.

Future activities: (*a*) Replenish its "stock pile" of scientific knowledge, for future application, which was reduced by diversion of regular staff and activities to war purposes for 5 years (*b*) accelerate exploration of coal reserves as to occurrence, bed characteristics, quality; (*c*) develop basic and applied knowledge of coal preparation in its essential phases; (*d*) continue development of mining methods and practices; (*e*) continue basic studies and surveys of carbonization and of coking properties of coals and blends; (*f*) study the rapidly expanding utilization of coal, through combustion, complete gasification, catalytic increase in heat value of gas, low-temperature carbonization; and (*g*) research and development of underground gasification methods to eliminate the necessity of mining difficult beds and conserve coal by utilizing all that is underground.

A. Coal-research activities of the Bureau of Mines during the national-defense and war periods

The peacetime activities of the Bureau of Mines in coal research, originating in 1904 and continued under the organic act of Congress establishing the Bureau in 1910, required no major changes to convert them to 100-percent war work. Almost every project that was in progress in 1940 served as a nucleus for solving some of the many technologic problems that arose in the rapid expansion that was required to meet the increased need for fuel, metallurgical coke, gas, and chemical byproducts required for explosives, synthetic rubber, and other war munitions.

A Solid Fuels Utilization for War Division was organized to assist the Solid Fuels Administrator for War by conducting the technologic and engineering work that was required by his office in meeting specific war problems relating to solid fuels. This Division gave special attention to the maintenance of the quality of coal by sampling and analyzing coal and coke that was suspected of being of

inferior quality. In such cases, engineering advice was given to the operators on improving their methods of mining and preparation. Advice also was given to power-plant and coke-oven operators on the use of substitute fuels when changes had to be made because of shortages in the usual supply.

An extensive national fuel efficiency program was organized in cooperation with national engineering societies and trade associations aimed at saving millions of tons of coal annually by an educational campaign on how to save fuel by more efficient combustion, the reduction of waste, and the prevention of heat losses.

In the field of coal mining, the Bureau studied problems of mine flood prevention and better methods of mining thin, steeply pitched beds that constitute a large part of our remaining reserves. The use of light earth-moving equipment for stripping coal from outcrops in mountainous areas was investigated. Studies were conducted on selective mining and surface blending of coals, on roof control, and on various problems of mechanization.

Bureau engineers planned and supervised exploration of coal deposits to determine the extent of minable reserves of coal in areas where there was a shortage of supply as in Alaska, Washington, and Oregon, and where coking coals were needed as in Utah, New Mexico, Colorado, and Wyoming to supply the new blast furnaces at Geneva, Utah, and Fontana, Calif. Laboratory petrographic examinations, chemical analyses, and coking tests were made in connection with field explorations and of other pertinent samples which might provide adequate fuel supplies to relieve acute shortages.

To provide additional supplies of high-rank coking coal and other special purpose coals whose reserves are limited, preparation studies were conducted on marginal and lower-rank coals. Methods of storing subbituminous coal without spontaneous heating and combustion were investigated.

The Bureau's continuing program of sampling and analysis of coal was expanded to provide service to the multitude of wartime installations and many new and additional data on the composition, constitution, and properties of coals from all parts of the country were collected and disseminated.

Conduct of a survey of the coking properties of American coals, begun some years before the war, was intensified to provide invaluable information to coke producers and consumers. A coke-production survey was initiated with the aid of an advisory committee of representatives of industry, the War Production Board, and the Solid Fuels Administration for War to maintain the output of pig iron at the maximum production capacity of existing blast furnaces by improving the quality and increasing the quantity of metallurgical coke production.

Utilization of the vast deposits of lignite and subbituminous coals of the West was considered, since these coals are capable of yielding a high-hydrogen gas for the direct reduction of iron ores as well as carbon monoxide and hydrogen.

Under wartime exigencies it was imperative that boilers be operated continuously at high rates. This threw into important focus the Bureau of Mines research on the combustion characteristics of various coals, particularly that relating to the clinkering and slagging actions of coal ash—an acute source of boiler "outage" under heavy continuous operation.

B. ACCOMPLISHMENTS OF THE COAL RESEARCH ACTIVITIES OF THE BUREAU OF MINES DURING THE NATIONAL DEFENSE AND WAR PERIODS

Composition, constitution, and properties of coal and coke

A force of trained inspectors collected thousands of samples for analysis at mines, Army posts, and other points of delivery in connection with the purchase of coal for Government agencies. War Department purchases alone increased from 1,000,000 tons per year before the war to 10,000,000 tons in 1943. Similar service was given to the Office of the Solid Fuels Administration for War in sampling new strip mines and fuel reclaimed from old dumps and anthracite culm banks. Such supervision served to prevent the sale of fuel that contained too much ash to be usable. The analytical and coal constitution laboratories handled approximately 2,000 samples per month, including all service work and the analytical work required in coal-mine inspections, exploration of coal deposits for increasing production, and research conducted on the combustion, carbonization, and liquefaction of coals.

Mining of coal

Coal production was increased in the face of declining manpower by spreading information on mechanization of mining and by encouraging stripping operations with whatever earth-moving equipment was available in various localities.

Bureau of Mines engineers studied selective mining and surface blending of metallurgical coal as developed in certain mines and reported these findings for application in other mines for increasing output and improving quality of coal for the production of coke. Studies of the influence of air conditioning on roof control resulted in decrease of roof falls in certain mines and thus aided in avoiding loss of production from roof falls of shale.

Exploration of coal deposits

Exploratory drilling of coal deposits in southwestern Wyoming and Gunnison County, Colo., proved millions of tons of additional coking coal for western steel plants. Drilling in Alaska provided immediate additional supplies of much-needed bituminous coal for use of Army posts and minable reserves of low-rank coals were established in the Coos Bay field of Oregon, another region where a critical shortage of fuel existed at the outbreak of the war. A deposit of lignite in Washington, minable at low cost by stripping methods, was also proved. A small but significant reserve of low-volatile coal, useful for blending with high-volatile coal for the production of metallurgical coke, was developed in Alabama.

The tonnages of coal reserves proved by Bureau of Mines field investigations from 1941 through 1945 and the cost of such investigations may be summarized as follows:

Project	Reserves	Total cost
Kemmerer, Lincoln County, Wyo	[1] 15,300,000	$81,940
Mount Pleasant, Sanpete County, Utah	(2)	36,961
Madrid, N. Mex	(3)	25,200
Coos Bay field, Oreg	[2] 10,809,000 [4] 6,193,000	117,689
Toledo, Lewis County, Wash	[2] 8,031,000	43,081
Coaldale, Nev	(5)	37,928
Minnesota Creek area, Gunnison County, Colo	[6] 624,000,000	61,562
Newport and Providence Counties, R. I	(7)	27,245
Matanuska, Alaska	[6] 2,400,000	34,561
Georges Creek field, Md	[6] 500,000,000	54,103
Coosa field, Ala	[6] 14,000,000	108,060
Fort Payne area, Ala	[2] 7,000,000	36,557
Coal Creek area, Gunnison County, Colo	[8] 70,000,000 [9] 70,000,000	160,626

[1] To determine coking quality of coal.
[2] Measured.
[3] No reserves established.
[4] Indicated and inferred.
[5] Beds not continuous; no estimate.
[6] Indicated.
[7] No reserves proved.
[8] Indicated, noncoking.
[9] Indicated, coking.

Preparation of coal

Technical service given by Bureau coal preparation engineers from the Pittsburgh, Pa., Tuscaloosa, Ala., and Seattle, Wash., experiment stations, aided materially in the maintenance of low ash and low sulfur in the coal supplied for the manufacture of metallurgical coke and in preventing excessive proportions of ash in coal generally, as occurred so frequently in the previous war.

In the Birmingham district a new method somewhat similar to froth flotation was developed for cleaning and dewatering the sludge and slurry from coal washers. A usable fine coal was recovered.

A study was made and the results published on small coal jigs for mechanical cleaning of coal at truck mines and other small operations. The results of preparation studies coupled with studies of mining methods and mechanization wherever possible contributed in no small measure to the maintenance of adequate supplies of solid fuels in the war program.

Direct utilization of coal as a fuel

The fuel economy service to other Government agencies developed by the Bureau of Mines following the First World War was of immediate value in applying experienced technical and engineering assistance in the rapidly expanding Government fuel-using plants. These included power and heating plants in many new Goverment buildings, Army cantonments, and Federal housing projects. Cooperation was given to the War and Navy Departments in advising on equipment and fuels, and in the conditioning and treatment of boiler feed water to prevent scale formation and corrosion.

In cooperation with the Solid Fuels Administrator, technical advice was given to industrial consumers in the selection of suitable substitute fuels where the

usual supply was interrupted because of priority demands for more important war purposes. Combustion tests were made of mixtures of bituminous coal and anthracite fines which showed how the latter, which were available in considerable quantity, could be used to supplement the shortage of fuel in regions near the anthracite district of Pennsylvania. Another experimental investigation showed how mixtures of coal and oil could be used to supplement fuel oil in the period when the supply of fuel oil was inadequate.

In the early period of the war advice was given on how to store coal with minimum danger from spontaneous combustion and thus enable industrial plants to build up a reserve of coal during periods of excess production. In the latter period of the war when production was declining on account of declining manpower in the mines, the Bureau organized a national fuel efficiency program in cooperation with industry which, through a voluntary staff of some 5,000 fuel engineers, carried on a successful campaign on how to save fuel and conserve heat in practically every industrial establishment in the country. It is conservatively estimated that at least 5,000,000 tons of coal were saved per annum.

Production of coke, gas, and byproducts

Expansion of the coking industry from a production of 44,000,000 tons of coke in 1939 to 74,000,000 tons in 1944 taxed the available facilities of mines producing high-grade metallurgical coal. In addition, new sources of coking coal were needed west of the Mississippi River. Fortunately, the coal carbonization laboratory of the Bureau at Pittsburgh had initiated, some 15 years before the war, a survey of the coking properties of American coals. These data were available for the selection of suitable coals from Oklahoma for use in the new steel plants in Texas, and Utah coals for the new plants in Utah and California. Additional specific tests were made at Pittsburgh and at the Bureau's station in Golden, Colo. Also, a new accelerated oxidation test developed by the Bureau was used in evaluating the effect of storage on the coking properties of these coals. Blending tests indicated how the physical qualities of the coke could be improved by blending certain low-volatile coals with specific high-volatile coals in both Texas and eastern practice. The Bureau's tests also were useful in determining the yields of gas and important byproducts obtainable from various American coals in estimating the expanding properties of coals and blends of coals—an important consideration in avoiding injury to coke ovens by expansion of the charge of coal while it is being coked.

Early in the war program a coke-production survey was initiated with the aid of an advisory committee of representatives of industry, the War Production Board, and the Solid Fuels Administration for War. Bureau technologists visited the various coking plants and learned the best practices that had been developed in plants. This information was brought to the attention of all units in the industry through publications and personal visits. Aid was given in securing suitable coals where the supply was short. Advice was given on more suitable blends and on how to obtain the best-charging densities. The prompt publication of information collected at various coke-oven plants on innovations and improvements for increasing output and quality of blast-furnace coke aided greatly in meeting the increased demands for pig iron.

A mobile testing laboratory was developed which circulated among the newly reconstructed beehive coke-oven plants which were needed to supplement the supply from the byproduct plants. This staff helped the beehive operators, which usually had no technical staff of their own. In this manner the quality of the beehive plants was kept at a higher level than could have been maintained without it.

Tests by the Bureau's staff aided in supplementing the shortage of low-volatile coking coal by admixing small percentages of anthracite fines which were available and which were accumulating in the anthracite region in excess of demand.

A new type of retort was developed at Golden, Colo., and at Grand Forks, N. Dak., for the production of a high-hydrogen gas from lignite for the direct reduction of iron ore. This retort also shows promise for the production of carbon monoxide and hydrogen for the synthesis of liquid fuels.

C. ACTIVITIES THAT SHOULD BE CONDUCTED TO COMPLY WITH THE MANDATE IN PUBLIC LAW 520. (STRATEGIC AND CRITICAL MATERIALS STOCK-PILING ACT OF JULY 23, 1946)

The conversion of the technical activities of the Bureau of Mines to a peacetime basis with the view of fulfilling its function under the mandate of Public Law 520 is not simply a matter of resuming its peacetime activities in the public welfare.

This law calls for long-term programs looking to the essentialities of common defense and future industrial needs.

Wars exert vast changes on nations and people, and the economy, sociology, and technology of the country have undergone changes of far-reaching effects. Much new work is now necessary to adapt the scientific advances to the improvement of peacetime economy. Since much of the Bureau's time, which was ordinarily given to research, was devoted to wartime services, the foremost need is for replenishment of the Bureau's store of basic knowledge of the coals in our reserves and of scientific developments applicable to these coals destined for both near and further future use. Likewise, rapid depletion of many of our richest deposits of mineral resources, aggravated by huge war-expanded demands, has made it necessary to seek new reserves, to utilize poorer reserves, to check more closely the quality of product being utilized, to engage in cleaning or other preparatory treatment, and to adopt different methods of utilization.

Exploration of coal reserves[1]

The initial survey of coal reserves was made in 1912. Two great wars and 35 years of industrial consumption have occurred in the interim and these have made great depletions in available supplies of the better coking and low-ash and sulfur-bearing coals.

More specifically, extensive exploratory work in Alaska and the State of Washington is imperative; also, continued core-drilling exploration and accompanying evaluation studies in Maryland, North Carolina, and many of the States between the Mississippi River and the Great Divide. Coal preparation, carbonization, blending, and utilization studies on coals of the Eastern and Central States are in urgent need because of depletion as the result of the consumption of the last 35 years.

Accompanying the work of physical exploration must be a program which will include the taking of core drill samples, coal analysis, preparation tests, and evaluation studies involving carbonization or coking tests of the coal, both singly and in blended mixtures with other coals from reasonably adjacent areas.

Present data on coal reserves were prepared from a geologic point of view and do not consider the minable reserves. These minable reserves can be estimated only from average losses in past mining practice. The data on reserves do not disclose the purposes to which the coal can be used or the methods by which many of the coal deposits can be mined. It is advisable to continue coal exploration in the United States so that reserves of special coals can be discovered at a rate at least equaling the rate of depletion of known reserves, and there are large but undefined quantities of coal on public lands. The coal-exploration work would also be a part of a mineral inventory. Data obtained on private lands could be used to advantage in mining and marketing the coal from new deposits or new areas and data on coal in the public lands would be especially useful in indicating the returns that the United States should expect when that coal is mined. One exploratory project conducted by the Bureau during the war indicated a reserve of 12,000,000 tons on Government land. This reserve at the prevailing royalty of 15 cents a ton represents a potential income of $1,800,000 to the Government with exploration costs of only $70,000. Another project has already indicated over 500,000,000 tons of coal on Government lands. Wise expenditure of even $750,000 each year for 10 years could be well be made. After 10 years, the program may have to be modified or expanded, depending upon the results obtained.

Coal preparation

Whereas in 1925 it was necessary for only 5 percent of the coal mined to be washed and otherwise cleaned for market and use, in both 1947 and 1946, because of rising demands and increasing impurities of coal as mined, 25.6 percent was cleaned in one manner or another. There is need in this field for both research in methods of cleaning and in application to various coals, not only with respect to changes in coal within beds and from bed to bed but to the many varieties of end use, e. g., domestic use, industrial power production, for coke production, for hydrogenation processes, for gasification processes, etc.

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[1] For a more complete discussion, see Coking Coal Reserves and Problems Confronting the Coke Industry, a Report for Army-Navy Munitions Board, by Arno C. Fieldner, Chief, Fuels and Explosives Branch, Bureau of Mines, U. S. Department of the Interior, March 27, 1947.

Further possibilities are believed to exist in coal preparation from the standpoint of conservation in lessening the loss of 20 to 30 percent of coal now left in mines and in reclaiming of coal values in other current wastes by present mining and preparation practices and there is not excluded from recovery much combustible material in present waste piles and culm.

Continuation of strip mining and continued use of lower-grade, high-ash coals, as the better grades are exhausted, are going to require continued coal preparation work to develop satisfactory and inexpensive means of reducing the proportions of ash, sulfur, and other harmful constituents of coals to make them salable for fuels, coking, gasification, and chemical manufacture. Increasing use of coal as an industrial raw material gives coal preparation work increasing importance since undesirable constituents must be removed by beneficiation to make the coal suitable for such use.

The development of new coal fields to serve the new metallurgical industries of the West and the necessity of utilizing the large reserves of poorer coals near the older and larger metallurgical areas of the East will present a wide variety of preparatory problems.

Mining methods and practices

Continued research in mining methods and in mine mechanization is essential from the standpoints of conservation and of economics. This need applies to anthracite, bituminous, and subbituminous, and lignite ranks. It is a continuing need due to differences in conditions of occurrence, overburden, coal properties and rank.

This problem could be divided into four separate parts:

(*a*) Survey of coal lost in underground mining. The latest report on coal losses was issued in 1923. At that time a loss of 35 percent for bituminous coal and 39 percent for anthracite was estimated. Changes in mining practice may have increased or decreased these losses; therefore, a field survey is necessary to determine the extent of loss in planning research and recommending changes.

(*b*) The methods and practices in underground coal mining with the various types of coal, thickness of seam, type of roof and floor must be studied and information on good and bad practices made available to the public so that the maximum coal can be removed with optimum economy.

(*c*) In strip mining, land is destroyed. It is imperative that a study of strip-mining methods and practices be made, especially with reference to the reclamation of land.

(*d*) In many coal fields mining in a single bed has been carried on while coal in subadjacent beds has not been recovered. Economic safe methods of mining two or more beds in the same field must be developed to conserve the coal.

These studies include the continuing work in the Bureau's experimental mine.

Experimental bituminous-coal mine and dust explosions.—This is a continuing project that has been carried on for years by the Bureau with resulting improvement in mine practice and safety. Adoption of new industrial techniques and creation thereby of new dust-explosion hazards requires trial techniques and requires continuing work on means for preventing dust explosions in mines, factories, and apparatus. More extensive use of the lower-rank fuels will also introduce new problems in mining and explosion prevention and control which can be solved in the Experimental mine.

Blending and carbonization

The decline in reserves of high-grade and high-rank coking coals brings to the forefront the importance of blending coals to obtain metallurgical coke of satisfactory quality. Blending affords a means of enlarging the country's coking-coal reserves by blending poorly coking coals with coals that are unusually rich in coking power. In many cases, a better coke can be obtained by a judicious blend of two or three different coals than can be made from any one of the three by itself. The blending of high- and low-volatile coals is common practice in order to obtain a strong coke, relatively free from shrinkage cracks, and a minimum of coke breeze. In the future, the problem of blending will be much greater, due to shortage of the most desirable coals. This need is being recognized by industry and much more attention is being given to research with experimental small- and full-scale ovens, primarily for the determination of the physical properties of cokes obtainable with various blends of coals, including research on the expanding properties of the coal charge and the effect of various size consists of the charge.

Some years before the beginning of World War II, the Bureau of Mines started an experimental study of the gas-, coke-, and byproduct-making properties of American coals. A method using 100 to 200 pounds of coal heated in a cyclindrical iron retort was developed in cooperation with the American Gas Association. This procedure, known as the Bureau of Mines-American Gas Association (BM-AGA) method was applied to a survey of American coals and a number of publications of the Bureau have been issued giving the yields and quality of the products obtained at various carbonization temperatures ranging from low- to high-temperature practice. These data were of immediate value when it suddenly became necessary to select coking coals from the Oklahoma-Arkansas field for supply the wartime blast furnaces and coke oven plants installed in Texas.

The Bureau of Mines has installed experimental slot-type ovens of about 400 pounds coal capacity at the Golden, Colo., Tuscaloosa, Ala., and Pittsburgh, Pa., experiment stations for conducting blending experiments with special reference to the physical properties of the resulting coke. Ovens of this size and type have been found to give results similar to those obtained in commercial scale byproduct ovens. At Tuscaloosa, studies are being started on blending the strongly coking coals of the southeastern portion of Warrior field with the weaker coking coals of the western and northwestern parts of the field. Such blending will be necessary in the future as the reserves of the better coals become depleted.

The Golden, Colo., experimental oven is planned for similar work on western coking coals. At this station some work also is being undertaken on blending noncoking bituminous coals with good coking coals.

Metallurgical coke from noncoking coals: At the Golden Station some small-scale laboratory experiments have been made on the production of coked briquets from mixtures of coking bituminous coal and noncoking bituminous coal or lignite char. The briquets were made by mixing and compressing about 15 percent coking bituminous coal, 8 percent pitch binder and 77 percent char obtained by the low-temperature carbonization of noncoking coal. The briquets were carbonized at high temperatures similar to those prevailing in coke ovens. Naturally, this three-stage process is more costly than the usual coking process, but it is technically feasible. A similar procedure has been described by A. Thau for use with the poorly or noncoking coals of Upper Silesia, in a report obtained by American investigators in their industrial intelligence mission to Germany.

More than 10 years ago, the Fuel Research Station of Great Britain showed that noncoking coals could be converted to coking coals by partial hydrogenation under pressure. Complete hydrogenation liquefies the coal, but properly controlled hydrogenation adds just enough hydrogen to the coal substance to give it the plastic properties of a coking coal. It is not impossible that research may develop a technically feasible method of producing coking coals for noncoking coals, and if small amounts of hydrogen will serve, it may not be impossibly costly for future use.

Mixtures of coal tar pitch, petroleum pitch, or heavy petroleum residuum and noncoking coal char or anthracite fines have been coked in laboratory tests yielding a porous strong metallurgical coke. From 30 to 40 percent of pitch is required. The pitch or residuum must supply a strong enough coke to hold together the inert particles of char and give the material a porous structure. This method could be used only under special conditions where large supplies of pitch are available concurrently with low-pitch char.

Large cities have been smoke conscious for more than a decade. Smoke abatement and the enforced use of the low-volatile fuels are being put into effect in a number of cities within the next few years. Fuel requirements for this purpose cannot be met by using anthracite and low-volatile bituminous coals. Freight cost in many instances would be prohibitive and the low-volatile bituminous coals in many instances are needed for metallurgical coke production. Low-temperature carbonization studies will indicate new sources of smokeless fuels which can also produce byproducts for the chemical industry.

Utilization of coal

The program of the Coal Division of the Bureau of Mines for the utilization of coal other than for the production of metallurgical coke is several-fold. From the standpoint of present and future conservation and economy, utilization efficiency is of front-rank interest. Combustion efficiency in power production is necessarily a continuing study as furnace design is advanced and coal from different sources and with different ash characteristics and slagging properties must be used.

As stated above, the currently definite progress in compulsory smoke abatement that is being put into force in certain of the cities makes much essential study of low-volatile coal, of low-temperature carbonization, and of combustion efficiency of coal in domestic consumption necessary. Much information service must be rendered in connection therewith.

Complete gasification of coals, particularly of the low-volatile, subbituminous, and lignite ranks, is in sight. Basic information on coals for this purpose is essential for the many problems which will arise in such processing. Complete gasification will enter into synthetic-fuels production, into domestic heating, and various industrial uses. The advent of smoke abatement, new industrial uses of hydrogen, increased demand for gas for domestic and industrial use, and expanding gas utilization by the chemical industries and the local depletion of natural-gas reserves indicate a greater need for manufactured gas in the near future. A large expansion in gas manufactured through coal-carbonization methods is limited by the market for the coke simultaneously produced. The production of gas by coking and subsequent gasification of the coke requires double handling and two sets of apparatus. The need for complete gasification, preferably continuous in one stage, has been evident for some time. A few experiments have been made and it is indicated that special apparatus must be developed. To develop the complete gasification of coal, especially high-ash coals or those unsuited for coking or other special purposes, through the laboratory and pilot-plant stages, will require sizable expenditures.

Another phase of complete gasification arises from the requirement that for many uses such as in domestic service, and for transmission economies, increases in heating value will have to be effected either in the process itself or in closely coupled units. Present-day developments in cheapening the production of oxygen, in combustion and processing under pressure, make this field of investigation one of great promise and significance. It is one that cannot in the common interest be neglected. Already the Bureau is being requested for information, assistance, and cooperation.

4. *Underground gasification of coal.*—Not all of the coal reserves in the United States can be mined economically with present practices or anticipated practices either because the coal is of poor quality or because it exists in beds that are too thin, too steeply pitched, or located in strata unfavorable to usual mining procedures. Underground gasification is one possible solution to the recovery of coal from these beds which cannot be mined economically. Meager available data on experiments made in Russia indicate that this method has great possibilities in providing low-cost fuel. It may also be useful to harness mine fires which cannot be extinguished and use the coal which is now being burned without gas recovery to produce gas for household and industrial use. This project would require the preliminary work, including sinking of shafts or holes and the connecting of these shafts or holes to start the gasification process and confine it to the selected parts of the coal bed.

The Bureau of Mines has cooperated with the Alabama Power Co. in one experiment in underground gasification at the Gorgas mine near Jasper, Ala. The data obtained are now being analyzed and much appears to have been learned.

The problem is admittedly complex, costly to investigate, and difficult, but the significance in conservation and economy is so great that the country cannot afford to fail to determine the possibilities of this process.

Petroleum, Natural Gas, and Helium

Early in the national defense period, the military services and other governmental agencies called on the Petroleum and Natural Gas Division of the Bureau for scientific and technologic information on petroleum and natural gas production problems and the composition of crude oils and base stocks for aviation gasoline. War accelerated these requests and the Division devoted its entire time to the war effort. As a result many surveys were conducted, field engineering studies made, and a great volume of data on aviation base stocks and blending factors were developed. This wealth of information was supplied promptly to interested governmental agencies such as the Petroleum Administration for War, and industry, to aid in the war effort. While this was being done, the Division was also making an equally outstanding record in producing helium, increasing the production rate by 1,150 percent through enlarging its only prewar plant and building four new helium plants early in the war period. At no time during the war did the Bureau fail to deliver helium in the desired quantities on schedule.

To comply with the mandate in Public Law 520, the Petroleum and Natural Gas Division should make engineering estimates of the Nation's reserves of crude oil and natural gas, as well as ascertain the rate of availability of these resources, make special engineering studies of condensate fields which are excellent sources of aviation fuels, expand its secondary recovery program, conduct research on methods for recovering petroleum from surface and near-surface deposits of oil-impregnated rocks, evaluate and survey the composition and characteristics of crude oils produced in the United States and foreign countries, conduct engineering studies on underground storage of natural gas and petroleum, and conduct a continuous survey to determine the helium resores of this Nation.

The Bureau of Mines, through the Petroleum and Natural Gas Division of the Fuels and Explosives Branch, conducts the Government's technologic research in the recovery, transportation, processing, and utilization of oil and gas. This division also produces all of the helium used in the United States for military, industrial, and other needs and conducts research on the occurrence, distribution, production, storage, and utilization of helium. These activities will be described immediately following the section dealing with petroleum and natural gas.

Beginning in 1940 the Army and Navy and other agencies concerned with national defense called for ever-increasing assistance from the Bureau of Mines on technologic problems relating to petroleum and natural gas. The tremendous importance of these natural resources in the event of war was recognized by Bureau engineers and their work was oriented toward meeting possible war demands long before the United States was drawn into World War II.

A functional classification of the activities of the Bureau of Mines with respect to technologic research on petroleum and natural gas during the national defense and war periods is briefly summarized in the following paragraphs under heading (*a*). Detailed descriptions of these acitivities and the results obtained are given under heading (*b*).

(*a*) *Technologic research of the Bureau of Mines in the petroleum and natural gas industries during the national defense and war periods beginning in 1940*

I. ACTIVITIES RELATING TO THE RESERVES, AVAILABILITY, PRODUCTION, STORAGE, AND TRANSPORTATION OF PETROLEUM AND NATURAL GAS

A. Surveys of sources and availability of petroleum and natural gas and of production, storage, and transportation facilities

Special surveys and reports on specific phases of the oil and gas industries were made by the Bureau of Mines throughout the entire period of national defense, war, and postwar activity. Many minor surveys and requests were met on a routine basis, largely because of the background of experience and files of technical data accumulated by the Bureau of Mines since the beginning in 1914 of its technologic research in oil and gas. Other surveys requiring additional information are as follows:

1. Collection and compilation of data pertaining to various oil fields in the United States.
2. Compilation of data on fires and explosions in the petroleum industry.
3. Survey of hazards to oil production, storage, and transportation facilities.
4. Survey of condensate fields in California.
5. Survey of potential sources of oil in the Rocky Mountain region.
6. Survey of needs in the Appalachian region for technologic research in oil recovery.
7. Report on availability of fuels for proposed aluminum plant in California.
8. Collaboration with Petroleum Administration for War on postwar report on underground storage of crude oil.

B. Engineering field reports

For many years engineering studies of typical oil and gas fields have been a regular activity of the Bureau of Mines. The many published reports of these field studies over a period of years comprise an invaluable backlog of information on various phases of oil and gas production. Because these reports cover typical fields, their value is not limited to the particular fields reported on, but extends to other fields of the same type. For this reason several universities use these Bureau of Mines engineering field reports in their petroleum engineering courses, and they are used as standard references by petroleum engineers throughout the country.

During the war, Bureau of Mines engineers who normally prepared engineering field reports on typical fields were engaged in specific war assignments. However, some of their previously prepared reports which were published during the national defense and war periods proved to be valuable and timely contributions to the war effort. These reports follow:

1. Report of Investigations 3456, Reservoir Characteristics of the Eunice Oil Field, Lea County, N. Mex.
2. Report of Investigations 3579, Petroleum Engineering Study of the Anahuac Field, Chambers County, Tex.
3. Report of Investigations 3712, Analysis of Oil Production in the Near-depleted Mexia-Powell Fault-line Fields of Texas.
4. Report of Investigations 3715, Engineering Study of the Rodessa Oil Field in Louisiana, Texas, and Arkansas.
5. Report of Investigations 3720, Petroleum Engineering Study of the Magnolia Oil Field, Columbia County, Ark.

Another timely engineering and geological report published in 1941 is the following Bureau of Mines bulletin published in cooperation with the Geological Survey:

6. Bulletin 418, Petroleum and Natural Gas Fields of Wyoming.

As specific war assignments the Bureau of Mines prepared several engineering field reports at the request of the Petroleum Administration for War. All of these reports were restricted and will not be published. Most of these reports covered condensate fields which were an important source for hydrocarbon components for use in aviation gasoline and to meet other war demands. Condensate field reports prepared by Bureau engineers and distributed on a restricted basis as specified by the Petroleum Administration for War, are as follows:

7. Engineering report on Logansport-Joaquin Field, De Soto Parish, La., and Shelby County, Tex.
8. Engineering report on Woodlawn Field, Jefferson Davis Parish, La.
9. Engineering report on South Elton Field, Jefferson Davis Parish, La.
10. Engineering report on Chapel Hill Field, Smith County, Tex.
11. Engineering report on Old Ocean Field, Brazoria County, Tex.
12. Engineering report on Sejita Field, Duval County, Tex.
13. Engineering report on Katy Field, Waller County, Tex.
14. Engineering report on Carthage Field, Panola County, Tex.
15. Engineering report on Lake Creek Field, Montgomery County, Tex.
16. Engineering report on Seeligson Field, Jim Wells and Kleberg Counties, Tex.
17. Engineering report on Paradise Field, St. Charles Parish, La.
18. Engineering report on Sheridan Field, Colorado County, Tex.

Additional engineering field studies made by Bureau engineers at the request of the Petroleum Administration for War are as follows:

19. Engineering study of the West Cement Gas Field, Caddo County, Okla.
20. Engineering study of the McCallum Dome, Jackson County, Colo.

C. Stimulative methods of oil recovery

As the impact of war made itself felt more and more in the demands for petroleum products, the need for extracting every possible barrel of oil from the sands in partly depleted fields became a major problem of the petroleum industry. Stimulative methods by the injection of air and gas and water into underground reservoirs was no new field of activity for the engineers of the Bureau of Mines, as they, for nearly 30 years, have been studying these methods of production. Some of the first work on this problem was done in the partly depleted fields in the Appalachian region before the First World War and the results of the study published as Bureau of Mines Bulletin 148 in 1917. Since then a continuous research has been maintained to develop new facts regarding secondary-recovery techniques, and about 1924 a secondary-recovery laboratory to obtain basic scientific data was started at the petroleum experiment station, Bartlesville, Okla. Growing out of these initial studies, engineers of the Bureau have continued to conduct field and laboratory experimentations along a broad front dealing with such studies as the systematic shooting and cleaning of wells, plugging back and water shut-off in wells, acidizing, reconditioning of wells, and operation of individual fields where air and gas or water have been used as repressuring mediums.

Activities of the Bureau of Mines in stimulating the recovery of oil in older fields and by secondary-recovery methods, during the national defense and war

periods, is best illustrated by the following list of Bureau of Mines publications on these subjects during that period.

1. Report of Investigations 3445, Effect of Acid Treatment upon the Ultimate Recovery of Oil from Some Limestone Fields of Kansas.

2. Report of Investigations 3573, Use of Brine in a Kansas Field for the Secondary Recovery of Oil.

3. Report of Investigations 3706, Some Tools and Methods Used in Cleaning Oil Wells in California.

4. Report of Investigations 3728, History of Water Flooding of Oil Sands in Oklahoma.

5. Report of Investigations 3761, History of Water Flooding of Oil Sands in Kansas.

6. Report of Investigations 3777, Wartime Application of Air-Gas Injections and Oil-Well Reconditioning in the Appalachian Region.

7. Report of Investigations 3778, Water Flooding of Oil Sands in Illinois.

8. Report of Investigations 3779, Horizontal Drilling for Oil in Pennsylvania.

9. Report of Investigations 3783, Air and Gas Injection in the Oil Fields of Illinois.

10. Report of Investigations 3792, Water Flooding in the McClosky Limstone in Clay City Oil Field, Clay County, Ill.

11. Report of Investigations 3818, Gas Injection into the McClosky Limstone in the Griffin and New Harmony Oil Fields, Indiana and Illinois.

In addition to the foregoing published reports, Bureau of Mines engineers were frequently called upon during the war to suggest methods for increasing recovery from oil fields and for applying secondary recovery methods. In some fields, known secondary-recovery methods were not applicable and Bureau engineers were requested to make special investigations in an effort to increase recovery in such fields. Two such investigations are listed as follows:

12. Investigation of the effect of temperature on the gravity drainage of oil in the Kern River field, Kern County, Calif.

13. Preliminary study of methods for recovering heavy, viscous oil from near-surface oil-impregnated deposits (locally called tar sands) in California.

D. Technologic studies contributing to the war effort

Bureau of Mines contributions to the war effort in the solution of technologic problems arising in the production, storage, and transportation of oil and gas were not limited to the special surveys, engineering field reports, and stimulative methods of oil recovery listed in the foregoing sections. Many of the results of long-continuing research by the division helped in the major programs of defense and war, when questions concerning certain phases of oil and gas production, transportation, and storage of petroleum and natural gas were asked by the Army, Navy, Petroleum Administration for War, other governmental agencies, and the industry. Frequently, only partial answers could be given because the specific problem had not been completely solved, but usually the available information was enough for the immediate needs.

The three items below represent a few of the Bureau's long-time researches in oil and gas production that contributed to the war program. They are typical of many others that might be mentioned, which in one way or another led to greater recovery and availability of oil and gas needed for the war.

1. Reservoir performance and well spacing.
2. Oil-well drilling-fluid research.
3. Coring porous rocks under pressure without contamination by drilling fluids.

In addition to the long-time researches, two important new studies developed during the war as follows:

4. Internal corrosion in high-pressure wells.
5. Use of helium to trace the movement of gas injected into oil and gas deposits.

E. Miscellaneous war assignments

Throughout the national defense and war periods Bureau of Mines engineers in the Petroleum and Natural Gas Division were frequently called upon for help in the solution of various problems in which their specialized training was essential. Some of these problems required extensive study carrying over into the postwar period, while others were short-range problems requiring quick action for expediting the war program. Two important long-range problems were:

1. Recovery of oil from surface deposits of bituminous sands in California.
2. Petroleum engineering studies in Elk Hills field, Naval Petroleum Reserve No. 1, California.

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Among the many short-range problems handled the two following are typical:

3. Oil pollution of water impounded by Denison Dam, Okla. and Tex.
4. Adequacy of gas from McAllen Field, Hidalgo County, Tex., for fuel for proposed magnesium plant.

II. ACTIVITIES RELATING TO THE PROCESSING, UTILIZATION, PROPERTIES, AND STORAGE OF CRUDE OIL, NATURAL GAS, AND PETROLEUM PRODUCTS

A. Aircraft fuels studies and surveys

One of the vital factors in the winning of World War II was the effective utilization of petroleum for the production of aircraft fuels, and the Bureau of Mines directed many of its activities successfully to that end. The routine laboratory analysis of all domestic crude oils, carried on for many years by the Bureau of Mines, was continued and provided much basic material for the special studies requested of the Bureau by war agencies. The studies and surveys concerned with aircraft fuels are listed below:

1. Survey of crude oils for content of aviation gasoline base stock.
2. Survey of condensates for content of aviation gasoline base stock.
3. Studies of marginal aviation gasoline base stocks.
   (*a*) Production of aviation gasoline base stock by desulfurization of marginal stock.
   (*b*) Production of aviation gasoline base stock by superfractionation of marginal stock.
4. Blending studies of 100-octane aviation gasoline.
5. Survey of possible crude-oil sources for jet-propulsion fuels.
6. Studies of evaporation losses of aviation gasoline and components in standing storage.

B. Sources of toluene from petroleum

A survey of the natural and potential toluene content of a number of crude oils and condensates was completed by the Bureau of Mines in 1942 for the Office of the Petroleum Coordinator for War.

C. Thermodynamics of hydrocarbons

Studies of the fundamental thermodynamic properties of hydrocarbons of special military significance were completed.

D. Additional sources of petroleum waxes

Studies on a pilot-plant scale indicated that valuable wax for war packaging could be obtained from waste crude-oil residuum.

E. Refinery distribution and capacity

A comprehensive survey of the distribution, type, and capacity of petroleum refineries in the United States was made available to defense authorities in the latter part of 1941.

F. Miscellaneous studies and reports

The Petroleum and Natural Gas Division of the Bureau of Mines was able to render assistance to many Government agencies on specific problems relating to petroleum chemistry and refining as a result of its 30 years of work in the field of petroleum technology.

(a) Helium activities of the Petroleum and Natural Gas Division during the national defense and war periods

When Germany invaded Poland in September 1939, the only operative helium plant was the one near Amarillo, Tex., supplied with helium-bearing natural gas from the Government-owned Cliffside gas field. Bureau of Mines helium activities during the recent national defense and war periods were directed toward an augmentation of those facilities to meet immediate military requirements and at the same time assure substantial helium reserves for possible future emergencies.

These activities included (1) a continuous survey of natural-gas fields in the United States to determine their value as a source of supply for helium-bearing natural gas, (2) the acquisition of gas rights to enable the Government to process helium-bearing natural gas from fields selected as a result of the helium survey, (3) the construction of additional facilities at the Amarillo helium plant and four new helium-production plants, and (4) the production of helium for use in

inflating lighter-than-air craft and weather balloons, in range finders and other instruments, in helium-shielded arc welding of magnesium, aluminum, and stainless steel, in secret military activities, and for other purposes.

(b) Results obtained through technologic research by the Bureau of Mines in the petroleum and natural gas industries during the national defense and war periods beginning in 1940

I. RESULTS FROM TECHNOLOGIC RESEARCH RELATING TO THE RESERVES, AVAILABILITY, PRODUCTION, STORAGE, AND TRANSPORTATION OF PETROLEUM AND NATURAL GAS

A. Results from surveys of sources and availability of petroleum and natural gas and of production, storage, and transportation facilities

The special surveys and compilations of technical data listed under this classification in (*a*) were made to meet specific needs arising during the immediate prewar and war period. They were all related directly or indirectly to national defense or the prosecution of the war. The results were completely satisfactory for this purpose. The data obtained have added to the Bureau of Mines files for future reference. It is anticipated these data will be of some peacetime value.

B. Engineering field reports

Items 1 to 6 listed under this classification in (*a*) are regular Bureau of Mines technical publications and represent permanent contributions of value to the technology of production of petroleum and natural gas.

The restricted engineering reports on condensate fields prepared for the Petroleum Administration for War will be retained in the Bureau of Mines files for future reference. They served an essential wartime need in providing data on availability of aviation gasoline components and other war products, and were used as a basis for important decisions on allocations of scarce materials and equipment. However, they are now of limited value as the fields reported on were all in the early stages of development at the time the reports were made. For this reason most of these reports should be revised in the light of additional data revealed by subsequent development.

Two of these wartime reports are now being revised and will be published when the revision is complete and the data have been released. They are the reports on the Lake Creek field, Montgomery County, Tex., and the Sheridan field, Colorado County, Tex. Postwar engineering studies have also been made by Bureau of Mines engineeers on the Carthage field, Panola County, Tex.

Additional postwar engineering studies should be made and the results published on some of the other fields on which restricted reports were issued during the war. Included in such fields is the McCallum Dome, Jackson County, Colo.

C. Results from technologic research into stimulative methods of oil recovery

Both the wartime results and the permanent peacetime benefits of the Bureau of Mines work listed under this classification is (*a*) are probably greater than in any of the other classifications. This can be attributed to two predominant factors. First: The work under 11 of the 13 items listed in this classification in (*a*) has been fully described in regular Bureau of Mines publications having a wide circulation throughout the oil industry. These publications have been of outstanding value to the thousands of small operators throughout the country dependent upon stripper-well production. Second: The depletion of flush fileds during the war and the failure to find large new fields has awakened the industry to the need for greatly increased technologic research in secondary recovery and stimulative methods so that maximum recovery may be obtained from known deposits.

The Bureau of Mines is continuing its research work on the two items 12 and 13 in (*a*) on which no reports have been published. These studies to date show promise of great future value.

Because of its great importance to the future oil supply of the Nation, the Bureau of Mines research program on secondary recovery and stimulative methods should be substantially expanded in the postwar period.

D. Results from teehnologic studies contributing to the war effort

All of the research work performed under this classification in (*a*) not only contributed to the war effort, but it is of permanent value. Most of the results

have been published, as reflected in the following Bureau of Mines publications:

Technical papers numbered:

629. Collecting and Examining Subsurface Samples of Petroleum.
638. Photomicroscopy of Salt in Petroleum.

Reports of investigations numbered:

3474. Properties of a Petroleum Reservoir Liquid and its Residua with Applications of the Data to Producing Problems.
3479. Review of Cutler's Rules of Well Spacing.
3481. Progress Report on Bureau of Mines-API Pressure Core Barrel.
3493. Application of Well Test Data to the Study of a Specific Gas-Production Problem.
3514. Equilibrium Cell for Investigating Properties of Fluids from Petroleum and Natural Gas Reservoirs, with a Section on Hypothetical Phase Relations of Natural Hydrocarbon Mixtures.
3517. Determination of Total Water-soluble Chlorides in Petroleum.
3535. A Method for Determining the Water Content of Oil Sands.
3540. Measurements of Compressibility of Consolidated Oil-bearing Sandstones.
3549. Measuring Particle-size Distribution and Colloid Content of Oil-well Drilling Fields.
3590. Temperature of Natural-gas Pipe Lines and Seasonal Variation of Underground Temperatures.
3595. A Laboratory Study of Water Encroachment in Oil-filled Sand Columns.
3618. Review of the Heaving Shale Problem in the Gulf Coast Region.
3634. Oil-reservoir Behavior Based Upon Pressure-production Data.
3642. Specific Volumes and Phase-boundary Properties of Separator-gas and Liquid-hydrocarbon Mixtures.
3645. Correlation of Certain Properties of Oil-well Drilling-mud Fluids with Particle-size Distribution.
3657. Productivity of Oil Wells and Inherent Influence of Gas: Oil Ratios and Water Saturation.
3767. Application of Back-pressure Method for Determining Absolute Open-Flows of Large Gas Wells.
3772. Thermal Expansion of Pressure Samples of Hydrocarbon Liquids from Gas-condensate Wells.
3869. Recovery and Utilization of Oil from Oil Field Waste Emulsion.
4004. A Method for Determining Simultaneously the Oil and Water Saturations of Oil Sands.

Information circulars numbered:

7173. Technical Research by the Bureau of Mines in Oil and Gas Production, Refining, and Utilization.
7215. Vapor-pressure Chart for Volatile Hydrocarbons.
7242. Synthetic Rubber, Its Production from Petroleum, Coal, and Other Materials.
7314. Reclaiming Used Pipe for Oil-field Operations with Cement Lining.
7334. Method of Handling Hydrogen Sulfide Gas in the Elk Basin Oil Field of Wyoming. (In cooperation with the Health and Safety Branch of the Bureau of Mines.)

E. Results from miscellaneous war assignments

Although the short-range problems included in this classification in (*a*) were of principal value to the war program, the two long-range problems listed as items 1 and 2 in (*a*) have made a permanent contribution to petroleum technology.

With reference to item 2, Petroleum Engineering Studies in Elk Hills Field, Naval Petroleum Reserve No. 1, California, the Director of the Naval Petroleum Reserves wrote the Director of the Bureau of Mines as follows, shortly after VJ-day:

"I would like at this time to express my appreciation of the splendid cooperation that has been given to the Navy by the Bureau of Mines in assisting us to solve the many problems presented during our development of Naval Petroleum Reserve No. 1 in this critical war period just ended. Your efforts and the data supplied us have been of inestimable value."

A permanent contribution to petroleum technology growing out of this Elk Hills work was the use of helium as a tracer in oil reservoirs. This is described in Bureau of Mines Report of Investigations 3897, Helium Tracer Studies in the Elk Hills, Calif., Field. Another Bureau of Mines technical publication resulting from this wartime job for the Navy in Elk Hills is Report of Investigations 4054,

Special Studies of Reservoir Oils in Naval Petroleum Reserve No. 1, Elk Hills Field, Calif.

With reference to item 1 in (*a*) hereof entitled "Recovery of oil from surface deposits of bituminous sands in California." This project was instigated by the Petroleum Administration for War as a Nation-wide survey of bituminous deposits by the Geological Survey, and the development of methods of extracting the oil from such deposits by the Bureau of Mines. Fortunately the war ended before it became necessary to turn to these deposits to provide oil for war purposes. However, peacetime demands and scarcity of petroleum reserves impelled Bureau engineers to continue their research on this project. With respect to one large deposit in San Luis Obispo County, Calif., the laboratory investigations of the Bureau of Mines has progressed to the point that the construction of a pilot plant to test laboratory extraction methods appears warranted. As surface and near-surface bituminous deposits in the Western Hemisphere have been estimated by some authorities to contain 220,000,000,000 barrels of oil, a greatly expanded research program into methods for extracting the oil from such deposits should be undertaken.

II. ACCOMPLISHMENTS RELATING TO THE PROCESSING, UTILIZATION, PROPERTIES, AND STORAGE OF CRUDE OIL, NATURAL GAS, AND PETROLEUM PRODUCTS

In addition to the immediate results given below for this work, the Bureau of Mines has furthered the conservation of petroleum by adding to the technical knowledge of its composition, its conversion into useful products, and its more efficient utilization.

A. Aircraft fuels studies and surveys

1. *Survey of crude oils for content of aviation-gasoline base stock.*—At the request of the Advisory Commission to the Council of National Defense, the Petroleum and Natural Gas Division of the Bureau of Mines made a survey of over 225 domestic crude oils to determine their content of 91-octane-grade aviaton gasoline in the period from October 1940 to August 1941. Approximately 300 copies of a report summarizing this survey were distributed to officials of the Federal and State governments who were concerned with the supply of aviation gasoline, and to officials of oil companies manufacturing aviation gasoline.

During the war period, this report was supplemented by results of the analysis of an additional 126 crude oils to July 1, 1944, giving virtually complete coverage of all important fields in the country.

2. *Survey of condensates for content of aviation-gasoline base stock.*—As a part of the survey of sources of 91-octane-grade aviation gasoline, 26 samples were taken during the summer of 1941 from cycling plants in Louisiana and Texas by members of the Bureau's staff, and analyzed at the Bartlesville petroleum experiment station. A typewritten report, dated December 21, 1941, was transmitted to the Office of the Petroleum Coordinator for National Defense, and at a later date mimeographed copies were supplied to a restricted list comprising manufacturers of aviation gasoline and officials of Federal and State agencies who were concerned with problems of supply of aviation gasoline.

3. *Studies of marginal aviation gasoline base stocks.*—In the course of the analysis of crude oils, natural gasoline, and condensates with reference to their suitability as sources of aviation-gasoline base stock, a number of samples were found to yield fractions that met the requirements for base stock except for low octane rating or lead susceptibility, or both. Many of these samples represented fields of large daily production, and if means could be found to increase the octane rating and lead susceptibility, the potential supply of aviation gasoline would be increased markedly.

It was known that certain hydrocarbons have much higher octane ratings than others, and if methods could be developed to remove a portion or all of those constituents of an aviation-gasoline distillate that have low octane ratings, the octane rating of the remaining material could be utilized to its full value, and marginal base stocks would be converted into useful and desirable aviation gasoline distillates. The process of separating these useful fractions is known in the industry as "superfractionation."

The improvement of marginal base stocks could be attacked also as a problem in reduction or removal of sulfur compounds. The deleterious effect of sulfur compounds upon octane rating, and particularly on lead susceptibility, was known, but the necessity for virtually complete removal of sulfur compounds was not generally recognized in the petroleum industry.

(*a*) Production of aviation-gasoline base stock by desulfurization of marginal stock: Some of the distillates that were prepared in the survey of crude oils for aviation-gasoline content contained relatively high proportions of sulfur compounds. Most of these distillates had low octane ratings, and moreover the improvement in octane rating upon addition of tetraethyl lead (the lead susceptibility) was unusually small. It was known that octane rating and lead susceptibility are adversely affected by sulfur compounds, but at that time (1940–41) there was little quantitative information on the subject, and the relatively great influence of small proportions of certain sulfur compounds was not recognized generally in the industry.

Bureau of Mines Report of Investigations 3729, Effects of Desulfurization on the Lead Susceptibility of Distillates from Some Crude Oils from Texas, New Mexico, and Oklahoma, issued on a restricted basis in 1943, gave the results of the desulfurization of 30 distillates. This report indicated that 23 distillates could be desulfurized to produce over 6,000,000 barrels yearly of grades 87 and 91 aviation gasoline.

(*b*) Production of aviation-gasoline base stock by superfractionation of marginal stock: The laboratory superfractionation of a large number of samples showed that constituents of low octane rating could be separated from those having high ratings. In 1942 virtually no refiners had the necessary plant equipment for this work and the demands for material for the synthetic-rubber program and other war work precluded such construction, so that only a small amount of aviation base stock was prepared by this method, and this laboratory work was discontinued.

4. *Blending studies of 100-octane aviation gasoline.*—Even before the survey of aviation-gasoline base stocks was complete, a series of discussions between the Bureau of Mines and the Office of the Petroleum Coordinator had been started regarding additional work by the Bureau. These discussions, which had begun early in August 1941, culminated in a formal request by Ralph K. Davies, Deputy Petroleum Coordinator, on October 27, 1941, for the Bureau of Mines to make "a series of tests to determine the effectiveness of various blends of alkylate, base stocks, isopentane, and other materials." According to Mr. Davies, "this will be of great assistance in immediate plans to utilize most efficiently the various components of 100-octane aviation gasoline."

One hundred-octane aviation gasoline differs from "grade 91" aviation gasoline in that the latter is a product of straight distillation from crude oil, natural gasoline, or condensate, with addition of tetraethyl lead, whereas 100-octane aviation gasoline contains synthetic products prepared from petroleum, such as commercial isooctane or alkylate, as well as straight-run or synthetic "base stock" and small quantities of other materials, including tetraethyl lead, of the nature of additives to improve performance. In addition 100-octane aviation gasoline has a "rich-mixture" rating of 130 index number, whence the classification as "grade 130 aviation fuel."

Fortunately the Bureau had an excellent background of information from the recently completed base-stock survey which greatly simplified the problem of selection of stocks with which to work. The first complete blending report was submitted to the Petroleum Administration for War in September 1943 and 20 additional reports were completed by January 31, 1944.

5. *Survey of possible crude oil sources of jet-propulsion fuels.*—Identification of crude petroleums whose distillates might be refined to meet the requirements for jet-propulsion aircraft fuels was the last major wartime activity of the Petroleum and Natural Gas Division of the Bureau of Mines. The study was undertaken at the request of Mr. A. P. Frame, Director of Refining, Petroleum Administration for War, who wrote on behalf of the Army and the Navy to Dr. R. R. Sayers, Director of the Bureau of Mines, on March 5, 1945, requesting the Bureau's assistance. Mr. Frame's letter stressed the urgency of the problem, stating that this work should have priority over the Bureau's activities on other phases of the aviation-fuel program.

As it was believed that jet-propulsion fuels would fall within the boiling range 150°–600° F., the major part of the suggested study related to determining, for different crude oils, the characteristics of straight-run distillates in this boiling range. Particular emphasis was placed on the development of relatively simple correlations, based on these characteristics, between the specifications and the data obtainable from the Bureau of Mines routine crude oil analysis so that the many analyses made by the Bureau might be used as preliminary guides in selecting sources of suitable fuel.

On July 9, 1945, 75 percent of the work had been completed, and the final Report on Possible Crude Oil Sources for Jet-Propulsion Fuels was completed October 5, 1945, about 6½ months after the work was begun.

The correlation methods developed from a study of the data of these distillations were applied to routine analyses of crude oils from the 30 fields in the United States that produced 25,000 barrels a day or more during 1944. Of this group, 13 crude oils definitely appear to be good sources of jet-propulsion fuel based on present specifications, 13 are rejected for one reason or another, and 4 are classed as doubtful. The 13 oil fields that were found to be satisfactory had a daily potential production of more than 300,000 barrels of jet-propulsion aircraft fuel distillate in 1944.

6. *Studies of evaporation losses of aviation gasoline and components in standing storage.*—The Bureau of Mines, recognizing the importance of minimizing evaporation losses of aviation gasoline as larger quantities of this material must be stored, made studies at a large refinery in the Texas Panhandle area from March 1941 to July 1942 to determine by the direct-gaging method the magnitude of the losses, due to evaporation under different storage conditions. Proper storage of aviation gasoline is very important, not only because large supplies are being stored for military use, but because the specifications to which this fuel must conform are very rigid.

Evaporation-loss studies were made on approximately 150,000 barrels of blended aviation gasoline and 200,000 barrels of two special blending stocks for aviation gasoline. These fuels were stored in seven 55,000-barrel all-steel tanks of the cone- and breather-roof types. The tests showed that the losses sustained over the test periods were nominal, ranging from 0.04 to 0.24 percent per month, and the changes in the characteristics of the tank contents were not enough to affect the characteristics of the fuels.

Bureau of Mines Restricted Report of Investigations 3701, Evaporation Losses of Aviation Gasoline in Standing Storage, by Peter Grandone, was issued in May 1943.

B. Sources of toluene from petroleum

When the toluene requirements for explosives production became urgent in late 1942, the Office of the Petroleum Coordinator for War requested the Bureau to make a quick survey of a number of condensates as sources of natural and potential toluene, potential toluene being hydrocarbons that can be converted readily by proper refinery processes to toluene. In a period of approximately 2 weeks a report on the analysis of 16 samples of condensates and 2 of natural gasolines was completed, utilizing equipment both at Bartlesville, Okla., and at Laramie, Wyo.

C. Thermodynamics of hydrocarbons

For many years the petroleum chemists and refinery engineers of the Petroleum and Natural Gas Division of the Bureau of Mines have needed information on the fundamental physical and chemical properties of the hydrocarbons, the principal constituents of crude petroleum and petroleum products. It was not until July 2, 1942, when Ralph K. Davies, Deputy Petroleum Coordinator, requested of the Director of the Bureau of Mines that the Bureau undertake development and the perfection of a single-stage process for conversion of butane to butadiene that enough interest in fundamental data was aroused to enable the Bureau to obtain appropriations for personnel and equipment.

After the usual delays, the work was started in 1943 with the aid of equipment borrowed from the California Institute of Technology, the Bureau of Mines helium plant, Amarillo, Tex., and the regional laboratory of the Department of Agriculture at Peoria, Ill. Other intricate equipment was constructed by a highly skilled instrument maker and the technical personnel assigned to the studies at the petroleum experiment station, Bartlesville, Okla.

In the interval between July 1942 and April 1943 other workers had undertaken the study of butadiene production and the first work of the new section was the determination of the heats of combustion of 10 hydrocarbons of high molecular weight in the range of lubricating oils. This work was reported in the Journal of the American Chemical Society in September 1944.

D. Additional sources of petroleum waxes

On May 26, 1942, Robert E. Allen, Assistant Deputy Petroleum Coordinator, requested the Bureau of Mines to obtain information as to possibilities of rod

wax and other sources of petroleum waxes in oil fields to augment the supplies of waxes from refinery sources. The findings of Bureau of Mines engineers were reported to the Petroleum Administration for War in September 1942 and the Bureau was advised that the sources of additional supplies pointed out in its report should be investigated further.

Having only meager funds available the Bureau was enabled to assign only one refinery engineer to investigate the possibilities of augmenting supplies of petroleum waxes. This engineer developed on a laboratory scale a process for reclaiming oil and wax from accumulations of "tank bottoms," a mixture of oil, water, wax, and dirt that settles to the bottom of crude-oil storage tanks and is removed at intervals and accumulated in ponds. Ultimately the bottoms in the ponds are burned to make room for more tank bottoms and the process is repeated indefinitely.

The Congress appropriated $20,000 for the fiscal year beginning July 1, 1943, to permit the Bureau of Mines to build and operate a pilot plant to demonstrate the process developed on a laboratory scale at Bartlesville. The findings from pilot-plant operation are needed by industry before reclamation of this kind of material can be undertaken on a commercial scale from a number of "burning pits" in different parts of the country.

This work was summarized in Bureau of Mines Report of Investigations 3869, Recovery and Utilization of Oil From Oil-Field Waste Emulsion, by Joseph W. Horne, J. Wade Watkins, and Arthur Matzick, published in March 1946.

E. Refinery distribution and capacity

In 1940 the Petroleum and Natural Gas Division began a study of the distribution of petroleum refineries in the United States and a report as of January 1, 1941, Distribution of Petroleum Refineries in the United States, by N. A. C. Smith and O. C. Blade, showed that 57 refineries of large size have more than 60 percent of the total refining capacity of the country, and another group of 45 plants could refine an additional 14 percent. Thus 102 of the 561 refineries in the United States in 1940 had 74 percent of the country's crude-oil refining capacity. The report showed further that refining equipment having combined crude-oil charging capacity of 538,000 barrels a day was in shut-down status on January 1, 1941.

In the fall of 1941 the Bureau of Mines brought most of this information up to date at the request of the Advisory Commission to the Council of National Defense.

F. Miscellaneous studies and reports

Many persons in various Government agencies whose activities pertained to the petroleum industry frequently requested information and advice from the Bureau with reference to specific problems.

The Board of Economic Warfare (Foreign Economic Administration) made many inquiries relating to petroleum and other sources of liquid fuels. These included (1) a study of the possibilities of oil shale as a source of liquid fuel in Australia, (2) analysis of samples of Cuban gilsonite and liquid products made from it, and reports and consultations regarding the practicability of the proposed manufacture of gasoline and other fuels from gilsonite and asphalts of Cuba, and (3) analysis of crude oils from a new oil field in Brazil as a basis for designing equipment for refining the oil.

Methods of analysis were developed in connection with many of the major studies and data on the composition of many petroleum distillates were obtained which could not be published during the war by reason of restrictions and lack of personnel. Included in these reports are the following:

Rapid Method for the Determination of Benzene, Toluene, and Seven-Carbon-Atom Naphthenes in Crude Oils and Naphthas, by Walter Murphy and H. M. Thorne, Bureau of Mines restricted report, May 1944.

Determination of Aromatics, Naphthenes, and Paraffins by Refractometric Methods, by R. M. Gooding, N. G. Adams, and H. T. Rall, Industrial and Engineering Chemistry, volume 18, page 2 (1946).

Composition of Petroleum: Hydrocarbon Type Analyses of Ten Distillates Boiling Between 100°–600° F., by W. C. Holliman and H. M. Smith, to be published.

Other data obtained during the war period are being assembled and will be published as soon as possible.

(b) *Accomplishments under the helium program*

(1) *Helium survey*

As a result of the helium survey, enough helium-bearing natural gas was found to supply four new helium plants during their wartime operation, and an important new helium reserve was located.

Three of the new plants—at Exell, Tex.; Otis and Cunningham, Kans.—were supplied helium-bearing natural gas from privately controlled fields which are operated to meet fuel demands whether or not the helium is removed. If the helium is not extracted prior to consumption of the natural gas in fuel markets, it is lost forever. Thus the helium produced at those plants represented an important saving, and the Government-owned Cliffside field was not depleted unnecessarily.

The other helium plant was built near Shiprock, N. Mex., to process gas from the Rattlesnake field, where helium-bearing natural gas was found in June 1942. The natural gas in this field will not support combustion, but it contains about 7½ percent helium at almost 3,000 pounds per square inch pressure. The Conservation Branch of the Geological Survey, which has cooperated for many years with the Bureau of Mines in its survey for helium-bearing gases, provided the samples that disclosed this important deposit. The Rattlesnake field is second only to the Cliffside field in possibilities as a governmental reserve for helium production and conservation.

(2) *Acquisition of helium-bearing gas rights*

By December 1941 studies of the various gas fields had shown that the Channing area of the Panhandle (Tex.) gas field was the most favorable source of supply of gas for a new plant. The Otis and Cunningham fields in Kansas were the second and third choices, respectively. Rights to process gas from each of these fields were obtained. When the Rattlesnake deposit was found, the Bureau acquired enough rights in the field to meet war requirements, but those rights did not place the deposit in the status of a reserve to be drawn upon or held in the ground as the Government's needs require. Since 1942 the Bureau of Mines has been negotiating for satisfactory rights in the field, and suitable agreements have been made to that end with the Navajo Tribe of Indians and the Continental Oil Co. and the Santa Fe Corp., subject to ratification by Congress. H. R. 3372 to ratify the contracts now is being considered by the Committee on Public Lands, House of Representatives.

(3) *Construction of additional helium facilities*

In June 1940 the total capacity of the Bureau of Mines helium production facilities was the capacity of the Amarillo helium plant—2,000,000 cubic feet per month. At that time, the Bureau of Aeronautics, Navy Department, was authorized to increase its lighter-than-air activities, and the Bureau of Mines planned to drill an additional well in the Cliffside field to increase the supply of helium-bearing natural gas to the Amarillo plant accordingly. Thus began a struggle by the Bureau to keep pace with the demand for helium by the armed forces and other consumers—a successful struggle as recognized by the late Secretary of the Navy, Frank Knox, in a letter dated April 10, 1944.

"* * * At no time during the present emergency has it been necessary to curtail naval uses of helium or to revise plans for use of helium because of shortages or prospective shortages of helium."

Keeping up with the armed forces was not an easy task. In December 1940, the Bureau of Aeronautics estimated that its helium requirements would reach a peak of 18,000,000 cubic feet in the fiscal year 1944. During the same month, the Army Air Corps estimated that its requirements would not exceed 5,000,000 cubic feet annually, and the Weather Bureau predicted a peak requirement in its activities of 8,500,000 cubic feet annually in the fiscal years 1943, 1944, and 1945.

The Navy repeatedly revised its estimates upward. In June 1941, the Navy estimate indicated that a peak helium requirement of 3,200,000 cubic feet would be reached in August 1942 if 21 new airships were constructed, and a peak of 4,100,000 cubic feet would be reached in February 1944 if the Navy constructed 42 new airships. On July 30, 1941, the Navy estimate indicated a peak of 4,200,000 cubic feet in the month of October 1943 if 27 airships were constructed, and 5,150,000 cubic feet in the month of July 1945 if 48 airships were authorized. In April 1942, the estimate had risen to a peak of 9,350,000 cubic feet to occur in March 1944, and the following July a revised estimate indicated that 17,000,-

000 to 19,300,000 cubic feet of helium would be required by all consumers in the month of August 1943.

Each time, the Bureau would move to expand its helium-production facilities, revised estimates by the Navy would require further expansion. First the capacity of the Amarillo plant was increased from 2,000,000 cubic feet per month to 3,000,000 cubic feet. Then the Exell, Tex., plant, originally planned to have a capacity of 2,000,000 cubic feet of helium per month, was constructed with a capacity of 5,000,000 cubic feet per month. Both these plants operated at above capacity until plants at Otis and Cunningham, Kans., and at Shiprock, N. Mex. (each with a capacity of 4,000,000 cubic feet per month), could be constructed and put into operation.

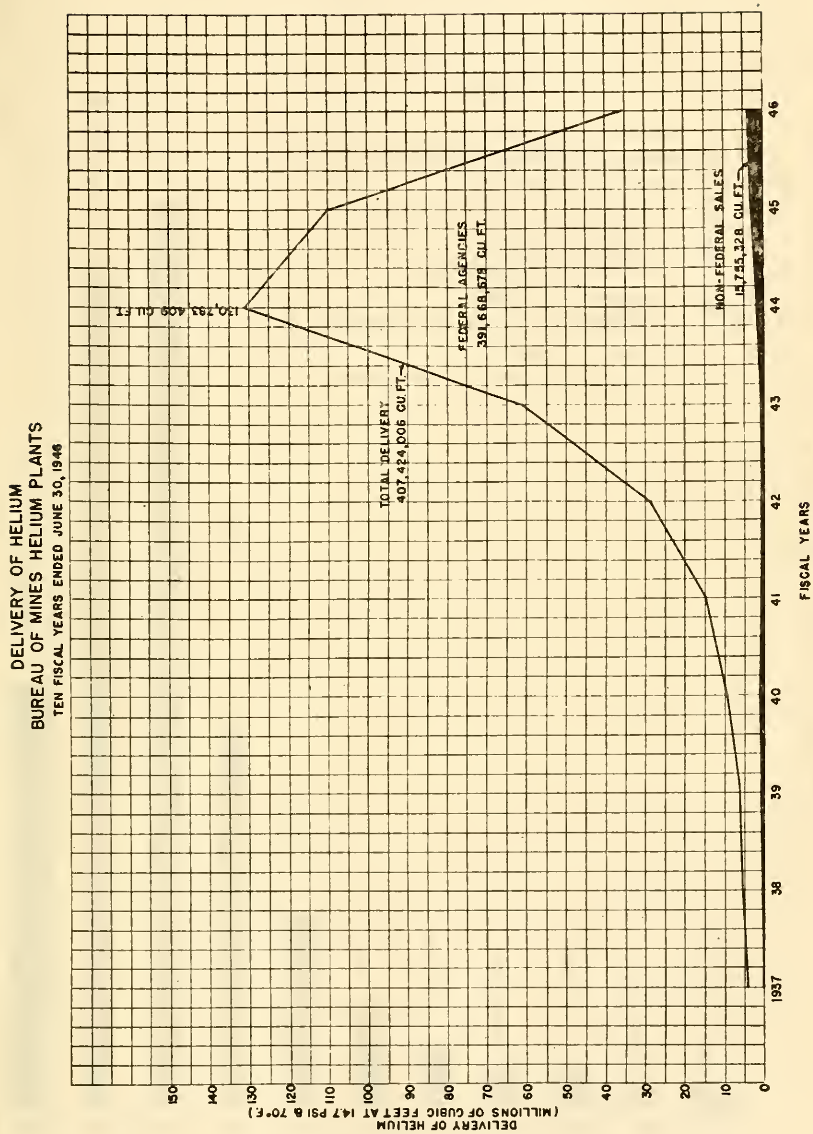
The success of the expansion program depended, to a great extent, upon efficient cooperation between the Bureau of Mines and the Bureau of Aeronautics, each working with full knowledge of the other's plans and complete understanding of the mutual problems.

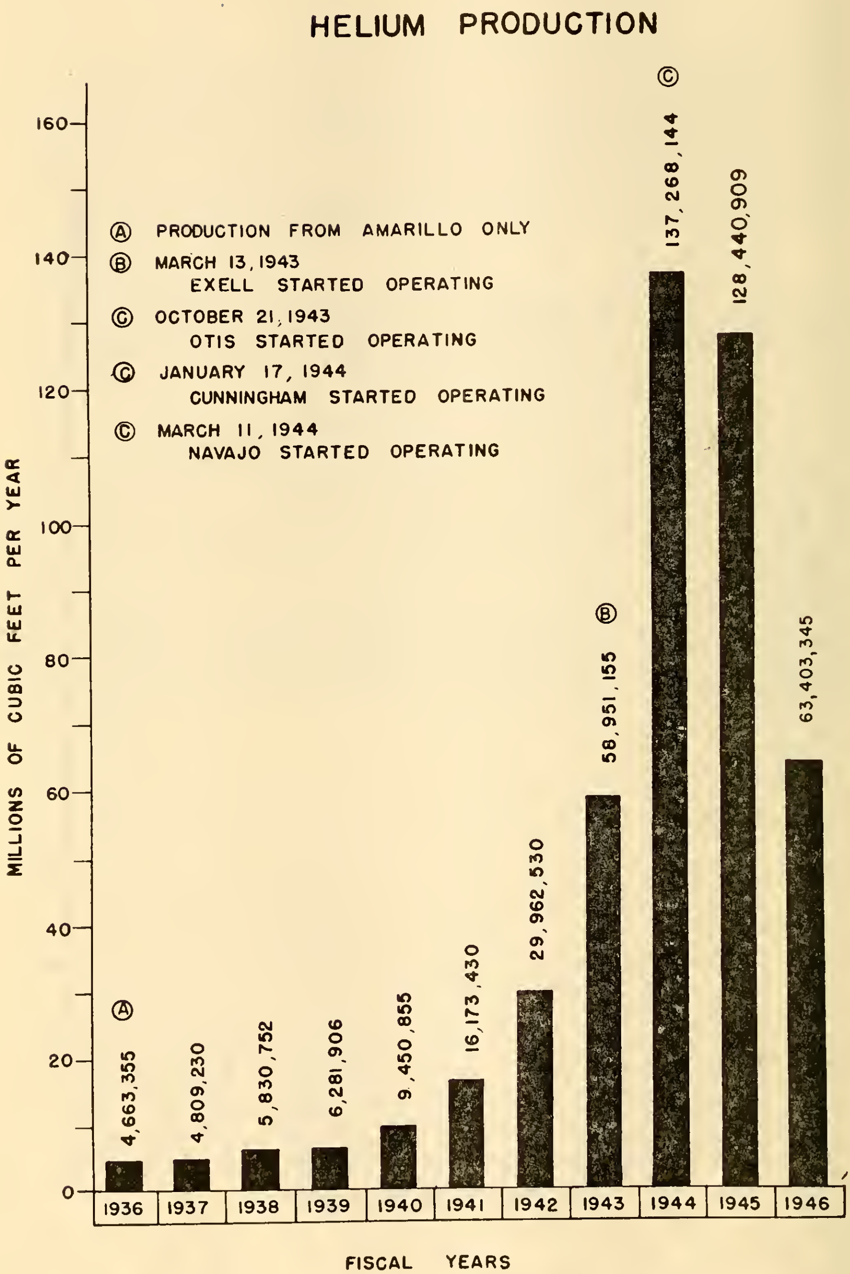
(4) *Production of helium*

The attached figures illustrate graphically the tremendous increase in the production and delivery of helium during the national defense and war periods. The peak demand for helium was reached in December 1943 when 14,454,000 cubic feet was delivered to the armed forces and other consumers. A total of 370,787,000 cubic feet was produced in the five fiscal years ended June 30, 1945. This is enough helium to inflate more than 600 patrol blimps of the latest type or 50 huge rigid-type dirigibles of the Graf Zeppelin II or Hindenburg class.

The Amarillo and Exell, Tex., helium plants each were given Army-Navy "E" awards on two occasions. The Otis, Kans., helium plant, which was put into operation later in the war, was granted one "E" award, and the Cunningham, Kans., plant was being considered for an award when the armistice was signed. The Navajo (Shiprock) plant did not get into operation in time to contribute substantially to the victory, but it stands today a bulwark against possible emergencies.

At the present time the plant at Exell is the only one that is producing helium. The Cunningham plant has been dismantled because of the impending depletion of the Cunningham gas field. The Otis plant is in stand-by status, but it also is faced with a possible shortage of helium-bearing gas in the next few years. The Amarillo and Navajo plants, served by the Cliffside and Rattlesnake fields, respectively, are in stand-by status to conserve the Government-controlled helium reserves.


DELIVERY OF HELIUM
BUREAU OF MINES HELIUM PLANTS
TEN FISCAL YEARS ENDED JUNE 30, 1946
130,783,409 CU FT
TOTAL DELIVERY
407,424,006 CU. FT.
FEDERAL AGENCIES
391,668,678 CU. FT.
NON-FEDERAL SALES
15,755,328 CU. FT.
DELIVERY OF HELIUM
(MILLIONS OF CUBIC FEET AT 14.7 PSI & 70°F.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
FISCAL YEARS
1937
38
39
40
41
42
43
44
45
46


HELIUM PRODUCTION
Ⓐ PRODUCTION FROM AMARILLO ONLY
Ⓑ MARCH 13, 1943
EXELL STARTED OPERATING
Ⓒ OCTOBER 21, 1943
OTIS STARTED OPERATING
Ⓒ JANUARY 17, 1944
CUNNINGHAM STARTED OPERATING
Ⓒ MARCH 11, 1944
NAVAJO STARTED OPERATING
MILLIONS OF CUBIC FEET PER YEAR
0
20
40
60
80
100
120
140
160
4,663,355
4,809,230
5,830,752
6,281,906
9,450,855
16,173,430
29,962,530
58,951,155
137,268,144
128,440,909
63,403,345
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
FISCAL YEARS

(c) *Petroleum and natural-gas activities that should be conducted to comply with the mandate of Public Law 520*

In enumerating and describing the activities that should be conducted to comply with Public Law 520, the Petroleum and Natural Gas Division presents an introductory statement to set forth the conditions now facing the Nation with respect to petroleum in relation to the history of this important natural resource immediately preceding and during the war period. For several years prior to the entry of the United States into World War II there was an actual or threatened oversupply of oil and gas in the United States. This actual or potential surplus of these natural resources created a feeling of security in the public mind with respect to the future available supply of oil and gas in this country despite warnings of dwindling recoverable reserves.

Shortly after Pearl Harbor it was realized that there would be no excess supply of oil in view of the tremendous demands of modern war on a world-wide scale. In fact, it was quickly evident that civilian consumption of gasoline and fuel oil would have to be restricted to essential uses in order to meet the ever-mounting demands of total war. This military and essential civilian demand necessitated compromises in the production, transportation, refining, and utilization of petroleum products. The country entered the war with a developed crude-oil producing capacity that exceeded the daily demand of that period by approximately 1,000,000 barrels per day. That reserve productive capacity has been used up in meeting increased demands. It is generally recognized that the present petroleum and natural-gas reserves will not last indefinitely. Although it is expected that additional new reserves will be discovered in this country, it is imperative that the Nation find out the extent of its existing reserves and how to recover, refine, and utilize them more efficiently.

Postwar America is enjoying a high rate of productive capacity, and this in turn requires a high energy demand. A critically important segment of this demand can be met only by ever-increasing supplies of oil and gas. The proved recoverable reserves of these strategic natural resources are wholly inadequate to meet such a demand either in their total amount or in the rate at which they can be produced, although the amounts of petroleum remaining in reservoirs after depletion by known methods are exceedingly great.

The over-all objective of the program of technologic research by the Petroleum and Natural Gas Division of the Bureau of Mines is the conservation of these hydrocarbon resources by the development of more efficient methods of producing, refining and utilizing petroleum and natural gas and their products. Now that the Nation has passed into the postwar period and figures can be looked at objectively, it is found that the total petroleum requirements were rising rapidly before the war; that they continued to rise during the war; that they are still higher now; and that all the while the trend has been just about on a straight line .

In the interests of national security, the United States must have available within its boundaries a large reserve of fuel and this can be accomplished best by the development of more efficient methods of producing, refining, and transportation in the petroleum industry. As mentioned previously, the United States had a productive capacity at the beginning of World War II which exceeded daily demands by about 1,000,000 barrels. At the present time military authorities are of the opinion that the Nation should have a reserve productive capacity of about 2,000,000 barrels per day to fight successfully a future war. Actually the country has little reserve productive capacity at this time and the small-sized discoveries made in recent years through wildcatting point to the importance of technology in increasing recovery efficiencies both by primary and secondary methods. To accomplish this increased efficiency in the production of oil, research is necessary to prevent premature abandonment of oil-productive property, to promote more efficient rates of oil production, and to increase the ultimate recovery of oil. In the refining industry, research must be continued and expanded to develop factual information on crude oils and their components that will lead to increased supplies and improved quality of aviation, jet propulsion, and Diesel fuels and other petroleum products. In the transportation and storage of petroleum, natural gas and their products, numerous improvements must be made to prevent waste and to promote greater efficiency of operation.

The wartime effort in supplying the military needs of aviation gasoline and other petroleum products for almost world-wide use has forcibly called attention to the large deposits of oil shale as a source of synthetic liquid fuels. In

addition there are known to be extensive surface and near-surface deposits of rocks impregnated with natural petroleum hydrocarbons requiring research to develop methods for their efficient extraction. These near-surface deposits are roughly estimated at several times the known underground petroleum reserve.

If the high-level economy of postwar America and the security of the Nation are not to be imperiled by a scarcity of petroleum and natural gas, it is essential that a broad program of applied research be inaugurated to increase the recovery and improve the utilization of these resources. This essential program, as envisioned by the Petroleum and Natural Gas Division of the Bureau of Mines, is briefly presented as follows:

The various projects might be logically arranged under the two broad categories of increased recovery and improved utilization of oil and gas in the United States. However, in order to show the relationship of this proposed program to the actual program, the projects are classified either as continuation and expansion of present activities (pt. I) or as new activities (pt. II).

PART I. CONTINUATION OF PRESENT ACTIVITIES

The program of the Bureau of Mines on petroleum and natural gas falls into five main technical classifications, and a sixth administrative classification for the Bartlesville Petroleum Experiment Station. These classifications are as follows:

1. Primary extraction of crude oil and natural gas.
2. Secondary recovery and development of oil-impregnated surface and near-surface deposits.
3. Transportation and storage of petroleum and natural gas.
4. Chemistry and refining of petroleum.
5. Thermodynamics of hydrocarbons.
6. Administration, operation, and maintenance, Petroleum Experiment Station, Bartlesville, Okla.

Each of the foregoing classifications will be briefly described with the objective, procedure, and justification outlined for each classification as contemplated in the proposed research program.

1. Primary extraction of crude oil and natural gas

Since the beginning of the oil industry in Pennsylvania in 1859, the United States has produced over 30,000,000,000 barrels of oil from approximately 3,000 fields throughout the country. The remaining recoverable reserves are estimated at 24,000,000,000 barrels. The production of oil for the 5-year war period, 1941 to 1945 inclusive, was nearly 8,000,000,000 barrels, or 1.3 times that of the previous 5 years. This high rate is continuing in peacetime, and it is manifest that if the demands for oil and gas are to be met, the remaining recoverable reserves must be produced in the most efficient manner. The objective of this phase of the program is to increase the recovery efficiency from these remaining reserves and from new discoveries.

This problem of primary recovery includes studies of reserve characteristics, optimum production rates for maximum recovery, well spacing, drilling, and completion techniques, reduction of waste and increased efficiency of production operations, and other related problems in the development of production of oil and gas.

The known primary recoverable oil reserves in the United States are an irreplaceable natural resource of inestimable value as they represent the cheapest and most available source of petroleum and natural gas. These remaining primary reserves plus the new reserves which will be discovered must be developed and produced in the most efficient manner if their full value to America in peacetime and war is to be realized.

2. Secondary recovery and development of oil-impregnated surface and near-surface deposits

After primary methods of extraction no longer recover oil from reservoir rocks at economic rates, most fields still are capable of yielding large quantities of oil by secondary methods. These operations require the application of energy by artificial means, which in primary recovery is supplied by nature, so that oil will move through the porous rocks to the wells. The work of the Bureau of Mines on secondary recovery problems is, among other things, to show the application of engineering principles to the recovery of additional oil and gas, thus increasing the known reserves of the country.

It is significant that though less than 1 percent of the past oil production has been by secondary methods, nearly 10 percent of the proved remaining recoverable oil in the United States is considered recoverable by proved secondary methods. In the postwar period there will be an increasing dependence upon these methods to meet the future demands for oil. In the expanded application of known methods of secondary recovery and the development of new methods, there is a tremendous field for research and an opportunity for increasing the recoverable oil reserves of the country by many millions of barrels.

Since 1917 the Bureau of Mines has been active in the investigation and development of secondary recovery methods as applied to the residual oil deposits of the United States. The volume of this activity has, of course, varied depending upon the funds and personnel available. Inasmuch as primary reserves are being depleted to a critical level by the demands of war, it is imperative that the Bureau's well-established program of research in secondary recovery be substantially expanded. Only by a wide program of applied research by industry, scientific institutions, and Government agencies such as the Bureau of Mines can the Nation be assured of an adequate supply of oil in the postwar years and provide reserves for future defense.

3. Transportation and storage of petroleum and natural gas

The function of the Bureau pertaining to this classification is best illustrated by naming the more important problems on which some work has been done and on which much more knowledge is needed. These problems are the delivery of crude oil from wells to field stock tanks and to refining centers, the transportation of petroleum products, such as gasoline, from refineries to marketing centers, losses of petroleum products by evaporation, and the application of the physical laws governing flow of fluids through pipe lines.

Problems pertaining to natural gas include the movement of natural gas from wells, fields, or natural-gasoline plants to retail marketing centers, and the formation of gas hydrates in high-pressure gas-transmission lines and methods of preventing their formation. In addition, this classification includes studies of the corrosion of oil- and gas-transportation systems, most efficient sizes and operating pressures of pipe lines, control of stray electric currents to minimize electrolysis of pipe lines, and many others.

The Bureau has long been outstanding in studies of evaporation losses of crude petroleum and its products. Because of new developments in gasolines, as well as improvements in storage tanks and oil-handling equipment, the Bureau should immediately resume active studies on the evaporation losses of crude oil and gasolines, including evaporation losses at retail outlets.

4. Chemistry and refining of petroleum

The long-established objective of Bureau of Mines research in the chemistry and refining of petroleum is to point the way to the more efficient utilization of petroleum through the application of fundamental principles of chemistry and refining technology.

Today's highly efficient aviation gasolines are "built" of numerous hydrocarbons to meet certain requirements, whereas during the first war they merely were closely controlled straight-run products. Present emphasis on "building" a fuel means that there must be knowledge of the type and characteristics of the several components in the final blend. It follows that two lines of investigation are of importance to the technique of formulating superior aviation, jet propulsion, and high-speed Diesel fuels: (1) Development of precise methods for analyzing hydrocarbons; and (2) determination of the effect of each component of the fuel upon the properties of the fuel.

One of the stumbling blocks in developing processes for the removal of sulfur from petroleum is lack of adequate knowledge as to what sulfur compounds are present in a given oil. Such knowledge is important in evaluating the worth and economic practicability of sulfur-removal methods as it has been determined that some sulfur compounds are very injurious while the effect of others is negligible. Adequate analytical methods must be devised for identifying and determining amounts of sulfur compounds. More and more the refiners are being forced to use so-called marginal high-sulfur crude oils in meeting the high demands.

The foregoing summary relates only a few of the many problems under this classification covering analysis of petroleum and application of chemical engineering in the manufacture of petroleum products.

5. Thermodynamics of hydrocarbons

The prime function of this research is to determine thermodynamic data on hydrocarbons and derivatives so that oil refiners and manufacturers of a wide variety of chemical products from petroleum will not be hampered in their operations because of the lack of reliable data pertaining to the most suitable temperatures, pressures, and other conditions that will give maximum practical yields. Thermodynamic data on pure hydrocarbon compounds are a continuing need of the industry to determine how far a chemical reaction will proceed toward completion at a given temperature.

6. Administration, operation, and maintenance, petroleum experiment station, Bartlesville, Okla.

The petroleum experiment station at Bartlesville, Okla., has occupied a dominant position in the laboratory work and much of the field work of the Bureau. For this reason a separate item is set up for the administration of this station. This makes it possible for the station to operate efficiently and render the maximum service and assistance to the five technical functions described above.

PART II. NEW ACTIVITIES TO BE CONDUCTED

1. Studies of the Nation's reserves of crude oil and natural gas

A. Methods of estimating reserves.
B. Engineering estimates of crude-oil and natural-gas reserves.
C. Availability of crude oil and natural gas.

Studies of the Nation's reserves of crude oil and natural gas are essential to the broad program of the Bureau in promoting conservation and efficient utilization of oil and gas. These studies of reserves require first detailed study of the various methods of estimating reserves to differentiate between them and outline the conditions under which each method or combination of methods are applicable. Once the application of various methods of estimating reserves is determined, the engineering estimates of the Nation's crude-oil and natural gas reserves can be started, and data can be accumulated on their availability.

Present methods for accumulating data on crude-oil and natural-gas reserves and their availability are not satisfactory. Government agencies must rely on data accumulated by American Petroleum Institute committees or by trade journals. Without details on procedures used in developing the data, full agreement with and reliance on the data at times might be questioned. Many situations have developed in the past when the Bureau of Mines and other governmental agencies have needed estimates of reserves and their availability, with the details that are available only from having developed the estimates. Had this information been available at the beginning of the national defense, the oil industry could immediately have operated with complete engineering control and with the least possible damage to known reserves.

2. Detailed studies of condensate fields and their behavior

During the war, condensate-type fields were of prime importance because the liquid components from them are used extensively in the manufacture of aviation gasoline. This type of accumulation, which occurs in deep, high-pressure deposits, has been discovered and produced in recent years as a result of technical advances in drilling and pressure control. Relatively little is known of the characteristics of the many condensate fields discovered to date, and undoubtedly many additional fields of this type will be found in the future. Extensive studies in condensate fields are required to prevent condensation in the reservoir and loss of these light components required for aviation gasoline. One of the important contributions of the Bureau of Mines to the prosecution of the war was the study of specific condensate fields.

3. Recovery of oil from surface and near-surface deposits of oil-impregnated rocks by mining and other methods

The objective of this activity is to develop new methods for the recovery of natural petroleum from oil-impregnated deposits throughout the Nation. Some of these deposits have been worked on a small scale for recovering asphaltic materials but most of them are not being exploited for any purpose.

The Bureau proposes to expand the limited laboratory experiments provided for in the current program on secondary recovery by investigating the possibilities of recovering oil from surface and near-surface deposits by open-cut and underground mining of such deposits. Extraction of oil may be accomplished by

drainage, by grinding the rocks, and washing, or by other means in conjunction with mining such as the application of heat or the use of solvents.

As the characteristics of both the rocks and the contained oil vary over wide limits in the various deposits throughout the country, additional laboratory and field investigations will be necessary on other deposits in order to build up an organized array of knowledge on the characteristics of these deposits and methods to be used for efficiently recovering the oil they contain.

The oil-impregnated sands and bituminous rock found in large quantities in surface and near-surface deposits throughout the country, constitute the most attractive source for new supplies of petroleum. The largest known deposit of this type in the world is the famous Athabaska tar sand deposit in Canada where the Canadian Government has inaugurated a long-time program of research and development on the extraction of oil from those sands. Similar type deposits are distributed in many areas of the United States and constitute potential petroleum reserves several times larger than our known underground reserves. In view of the future tremendous demand for oil in this country, an extensive research program is fully justified to develop methods for extraction of oil from these deposits. Continuation and expansion of investigations on oil recovery from these surface and subsurface deposits both on a laboratory and field scale is a very important postwar requirement.

4. Evaluation and survey of composition and characteristics of crude oils produced in the United States and foreign countries

To determine the composition and characteristics of the crude oil from individual fields comprising the 24,000,000,000-barrel reserve and from new fields of the United States and such foreign oils that may be important as a supply in our world operations.

The crude oil from each field will be subject to Hempel analysis for comparison with crudes from other fields and in addition will be minutely separated into components by fractionation in multiplate laboratory stills. This will permit the determination of the chemical and physical characteristics of the varions fractions. Complex crude oils containing components useful for the manufacture of special products as aviation gasoline blending stock, special lubricants, crystalline wax, asphalts, and Diesel fuels will be studied by subjecting them to treatment in a pilot plant and special chemical processes.

The war has conclusively demonstrated that this information was needed in correlating the Nation's refinery operations to produce aviation gasoline components. The present trend in refinery technique involves reconstructing the multiple hydrocarbon molecules into the required products. The industry has passed through its initial phase of cracking and fractionation and is now in the phase of producing products through chemical and physical change. The industry can be considered a chemical industry. It is imperative that a central agency such as the Bureau of Mines obtain the data on composition and characteristics of crudes so that the limited reserves may be conserved by using them to obtain the maximum special products.

5. Studies of underground storage of gas, petroleum, and products

It is proposed to study the application of underground storage of gas, petroleum, and their products to assist in overcoming shortages during peak demand periods. Underground storage has been used principally for gas to overcome peak demands during winter months, and several gas storage projects have been of inestimable benefit in maintaining adequate gas supplies to some war industries. Some use has been made of underground storage to store other hydrocarbons during periods of small demand or overproduction.

Work on this project will include detailed studies of the operation of storage projects now in operation and of proposed projects. Detailed analyses will be made of the storage reservoirs including the characteristics of the formation, the contained fluids, optimum working pressures, and other influencing factors.

6. Survey of Nation's oil-shale resources

This survey is needed to evaluate the potential reserves of petroleum contained in oil shales of the United States.

This survey will be made in cooperation with the Federal Geological Survey which will conduct geological studies to determine the location and extent of the oil-shale deposits. The Bureau of Mines will utilize this information in planning and carrying out a core drilling program to determine the thickness of the deposits, and to secure samples to be analyzed for their potential petroleum

content. With this information, the Bureau will evaluate the potential petroleum reserves in oil shale.

Under the Synthetic Liquid Fuels Act, selected deposits of oil shale will be developed sufficiently to demonstrate the value of such deposits as future reserves of liquid fuels. With the knowledge gained in these demonstration operations, all of the remaining oil shale deposits throughout the country can be evaluated after the proposed survey is completed, thereby providing a true estimate of the future value of these resources to the Nation. The potential oil reserves contained in oil shale are probably several times the prevent underground proven petroleum reserves.

(c) Helium activities of the Petroleum and Natural Gas Division that should be conducted to comply with the mandate of Public Law 520

The United States is the only nation that is known to have reserves of helium large enough to warrant commercial-sized production of this gas which has many military, naval, industrial, and medical uses. This gives the Nation a distinct advantage in many endeavors such as lighter-than-air craft for antisubmarine patrol and in welding aluminum, magnesium, and stainless steel for heavier-than-air craft.

1. Helium utilization and research

Research is being conducted to find new applications for helium and determine methods for utilizing its unique properties in medical, metallurgical, and other industrial uses. Investigations will be made on helium extraction and purification processes and transportation methods to improve them.

Helium is being used as an inert atmosphere for welding magnesium and alloy steels. This practice has been an important contribution to construction of war materials and it is proposed to investigate the use of helium in several metallurgical processes. These problems, if applicable, will result in improving processes by decreasing losses in melting, and improving the properties of the metals.

Bureau engineers devised the present helium-extraction process and it seems likely that methods and equipment can be improved that will improve the methods of extracting helium. It is important to develop methods and equipment for extracting helium from gases containing helium in quantities not now considered economically extractable. A considerable volume of helium is available in low-helium-content gases that can be extracted for use or for conservation in underground storage, if an economical method is developed for its extraction.

The transportation of helium from the plants to the point of use is an expensive item in the over-all cost to the ultimate consumer. Often the cost of transportation of helium in high-pressure steel containers is higher than the cost of production. The Bureau of Aeronautics has requested the Bureau of Mines to develop shipping containers and methods of preparing helium for shipment that will reduce the cost of transporting helium and reduce the burden on the railroads. This is especially important during war periods.

2. Survey of helium resources and engineering studies of new helium reserves

The objective of this survey is to locate new fields containing helium-bearing natural gas and make engineering studies of the reserves to determine their suitability for production of helium.

The Bureau of Mines has conducted the helium survey intermittently for 27 years and during that period has found few fields that are suitable from both the standpoints of helium content of the gas and reserves to make helium extraction feasible. The information about the suitability of a field for helium extraction must be determined at the beginning of a field's life; otherwise it will be used for commercial purposes without having the helium content of the gas extracted. Often, it is possible to extract the helium and use currently the residue gas without delaying its commercial use. In some cases, it is desirable to make arrangements to set the field aside as a helium reserve for future use. Helium has proved indispensable for war use and present developments indicate an important peacetime field in metallurgical and medical use. Therefore, the Bureau should always have current information on helium resources so that appropriate steps can be taken to conserve new helium discoveries.

SYNTHETIC LIQUID FUELS

Synthetic liquid fuels activities of the Bureau of Mines during the national defense period were on a small scale but laboratory equipment for coal hydrog-

enation was constructed during this period and various American coals were assayed. Research on catalysts for the gas-synthesis process was also conducted.

In 1944 following passage of Public Law 290 (78th Cong.) authorizing appropriations not to exceed $30,000,000 for a 5-year program, the Office of Synthetic Liquid Fuels was established in the Fuels and Explosives Branch and the work divided among seven divisions. During the war, plans were drawn up and construction started on necessary laboratories at Bruceton, Pa., and Laramie, Wyo. The oil-shale demonstration plant site at Rifle, Colo., was selected and construction of the mine and plant started. After an extensive survey, the Missouri ordnance works at Louisiana, Mo., was selected as a site for the demonstration plants using coal. Pending completion of the construction program, laboratory work was carried on effectively in temporary quarters at Pittsburgh, Pa., and Laramie, Wyo., and in space provided by the University of West Virginia, at Morgantown.

In spite of the operational difficulties of the very difficult war period, substantial progress was made in the laboratories. First-hand information on German processes was obtained by a mission to Europe before the end of the war.

To comply with the mandate of the Strategic and Critical Materials Stock-Piling Act (Public Law 520) the activities of the Office of Synthetic Liquid Fuels should be continued and expanded and, in addition, supplementary research projects should be established to make surveys and determine the minability of solid-fuel reserves, to study mining methods, to investigate chemical byproducts, to develop improved equipment that will reduce steel and manpower requirements, and to study the adaptability of synthetic fuels to various uses. Detailed project studies should also be made for commercial plants.

(a) Activities in synthetic liquid fuels during the national defense and war periods

Bureau of Mines activities in synthetic liquid fuels during the national defense period included work on coal hydrogenation with a laboratory-scale experimental plant that had been erected in 1936. It had a capacity of 100 pounds of coal per day yielding about 8 gallons of gasoline. The main objective of plant operations thus far had been to study the hydrogenating properties of coals from the more important coal beds in the United States. Sixteen coals were assayed. The assay consists in determining the maximum quantity of an oil containing 20 percent of gasoline and 80 percent of oils boiling below 650° F. which can be produced in a single pass through one converter.

In the experimental plant, coals that contained more than about 7 percent of ash were difficult to hydrogenate. It is also known from laboratory tests in small bombs that coals containing more than about 85 percent carbon are difficult to liquefy. It is therefore desirable to avoid high-ash and high-carbon coals in selecting a coal for liquefaction.

Low-ash subbituminous coals and lignite, which comprise 50 percent of the national coal reserves, were easy to liquefy, although the yields were only half that of high-rank bituminous coal. However, this lower yield may be compensated by low-cost strip mining.

Coal hydrogenation also provides an important source of organic chemicals of commercial value, such as tar acids (phenol, cresols, and xylenols) for plastics and benzol, toluol, and xylol for explosives manufacture and solvents. The yields of tar acids and tar bases are about 10 times those obtained in coal carbonization.

GAS SYNTHESIS

In 1928 to 1930 the Bureau of Mines developed an active iron-copper catalyst for the gas-synthesis process. Because of lack of funds, this research was discontinued. In 1942 funds were appropriated by Congress for further experimental work on this process. About 6 months of experimental work on iron and cobalt catalyst was done in 1942 to 1944, using three shifts a day and six catalyst-testing units. An engineering laboratory for development of process improvements and for pilot-plant operation on the scale of a few quarts of oil a day was completed and operated for about 8 months.

In spite of the fact that this testing was on a very small scale, the results were promising, both with respect to development of better catalysts and in the simplification of the engineering design of the plant.

This was the status of the Bureau of Mines research on synthetic liquid fuels at the end of the fiscal year ended June 30, 1944. It had been conducted on a purely laboratory scale to aid in the evaluation of foreign developments and to determine the suitability of American coals and lignites for these liquefaction processes. When the research was started in 1937, it was thought that American petroleum reserves were ample and that there would be no need for the early establishment of a synthetic liquid fuels industry. However, it was realized the time would come when gradual exhaustion of domestic petroleum reserves would require supplementing the constantly increasing demand for gasoline and Diesel oil with liquid fuels from other sources.

Since 1937 the rate of discovery of new pools of oil has declined materially and the World War has emphasized the fact that oil is the prime essential of modern warfare and that foreign sources of crude oil might not be available in another war. Congress recognized this situation and in 1944 passed Public Law 290 (58 Stat. 190, 30 U. S. C., secs. 321–325) authorizing the Secretary of the Interior, acting through the Bureau of Mines, to construct and operate demonstration plants to produce synthetic liquid fuels from coal, oil shales, agricultural and forestry products. This law was passed following hearings before a special subcommittee, in August 1943, in Washington, D. C.; Pittsburgh, Pa.; Salt Lake City, Utah; and Sheridan, Wyo. Testimony was given by 77 witnesses including representatives of Government, the oil and coal industries, and university and State research organizations. The geological, chemical, and engineering professions were well represented by leading members of these professions who had given special attention to the subjects under consideration. The printed proceedings of these hearings constitute a veritable mine of information on the national fuel reserves and various means of utilizing them for supplementing liquid fuels from petroleum.

ORGANIZATION OF WORK UNDER THE SYNTHETIC LIQUID FUELS ACT

Immediately following passage of Public Law 290 (authorizing the appropriation of not to exceed $30,000,000 during the next 5 years) in April 1944, the Bureau of Mines prepared plans and estimates for carrying out the work authorized. Congress granted an initial appropriation of $5,000,000 for the fiscal year ending June 30, 1945, to be available until expended with the 5-year limit. Conferences were held with representatives of the Department of Agriculture and arrangements were made for the Bureau of Agricultural and Industrial Chemistry of the Agricultural Research Administration for the erection and operation of a semiworks plan for the establishment of the technical feasibility and cost factors of a continuous process for the saccharification of agricultural residues to products from which alcohol liquid fuels can be produced by fermentation. This pilot plant has been constructed at the Northern Regional Research Laboratory at Peoria, Ill. The Bureau of Mines will study the utilization of agricultural and forestry products for producing liquid fuels by the hydrogenation and gas-synthesis processes in the same pilot and demonstration plants that will be used for coal and lignite, as the processes are essentially the same for all of these materials.

To carry out the complete program, the Office of Synthetic Liquid Fuels has been established in the Fuels and Explosives Branch of the Bureau of Mines. It includes the following divisions:

(1) Oil-Shale Retorting and Refining.
(2) Oil-Shale Mining.
(3) Research and Development (hydrogenation and gas synthesis).
(4) Synthesis Gas Production.
(5) Gas Synthesis Demonstration Plant.
(6) Hydrogenation Demonstration Plant.
(7) Foreign Synthetic Liquid Fuels.

OIL-SHALE DIVISIONS

The field activities of the oil-shale divisions are divided between the petroleum and oil-shale experiment station at Laramie, Wyo., and the oil-shale demonstration plant at Rifle, Colo. Research and development work is being conducted in a new building constructed during and following the war on Bureau of Mines property at Laramie. A site was selected and construction started on a demonstration plant to be operated at Rifle on Naval Oil Shale Reserve No. 1 to mine and process about 200 tons of oil shale a day.

Although many processes have been proposed for the recovery and refining of oil from oil shale, as revealed by nearly a thousand patents, in the United States none have been successful as commercial ventures and few have been found to operate with caking shales. Shale oil has long been considered a substitute for petroleum. However, special methods of extraction and refining must be devised through research to develop products that will be suitable for use along with those of petroleum. The main function of the research and development laboratory, therefore, is to conduct several types of studies correlated to provide a thorough insight into the physical character and chemical composition of oil shales from different States and shale oil derived thereform, and to determine the proper conditions for processing these materials and their products and byproducts to yield marketable commodities as economically as possible.

As the new building could not be completed before the end of 1945, a laboratory and office were established in a temporary frame building on the land donated by the University of Wyoming for the location of the new laboratory building. Preliminary research work was well under way on the examination of shale oils produced in two experimental retorts, which include a retort designed by V. F. Parry of the Bureau of Mines at Golden, Colo., for the gasification of coal. The shale oil from the Parry retort was produced to provide the Navy with material for experimental purposes in their survey of sources of Diesel and boiler fuel oils.

Petroleum is obtained as an organic liquid from holes drilled through the earth's surface to saturated oil-bearing sands. Oil shale contains organic matter, but it is solid and the only means found so far for converting this solid material to a liquid is some form of heat. One of the research projects to be investigated is a method for heating oil shale underground ultimately to drive out the oil. It is obvious that many difficult problems are involved in such a procedure; for example, regulating the degree of heat, the area to be heated, and providing the necessary means for collecting and draining oil from residual rock.

Oil-shale mining

It might be assumed that methods developed for coal and other minerals would be applicable to mining oil shale, but oil shale is not like coal. It is tough and, to a certain extent, elastic. The toughness of oil shale becomes most apparent in the crushing to suitable sizes for handling and processing. Therefore, an investigation on the mining of oil shale is an important part of the research and development program and will comprise a broad study of methods, equipment, and costs for large-scale mining of oil shales of various characteristics under a wide variety of conditions. This work will include the collection and analysis of data from commercial mines of various types, as well as from the mine at the oil-shale plant.

At the end of 1945 at Rifle, an oil-shale mine was opened and the haulage tunnel driven a distance of 300 feet. This mine will provide 100–150 tons of shale a day for the retorts. An important part of the mining operation is to develop low-cost methods of mining oil shale and to estimate the costs of mining on a large scale.

Core-drilling program

In cooperation with the Navy Department and the Geological Survey a core-drilling program was started on the oil-shale mine site during 1945. This work was needed to provide a sound basis for estimating the value of the oil-shale reserves and to supply important information on the oil-shale formations needed in planning and conducting the mining operations.

Navy Department cooperation

In planning and carrying on the oil-shale work the Bureau of Mines has enjoyed the full cooperation of the Navy Department. As a result of correspondence between the Secretary of the Navy and the Secretary of the Interior (Secretary of the Navy letter dated October 31, 1944, and the Secretary of the Interior letter dated November 16, 1944), there was established an Interdepartmental Board on Oil Shale. This board has played an important part in planning certain phases of the oil-shale program.

Research and Development Division

The necessary buildings for the development and pilot-plant work on the hydrogenation and gas-synthesis processes for coal are being erected on the Bureau of Mines experimental coal mine and explosives testing station property at Bruceton,

Pa. Six buildings, oil tanks, gas holders, coal bunkers, and other equipment occupy a 12-acre area on the 160-acre property.

The detailed design of the buildings has been completed and construction work started during 1945. The grading and installation of foundations were completed that year and steel work, boilers, and stack were being erected.

Detailed design, specification, and purchase were under way for equipment to install two 1-barrel-a-day gas-synthesis pilot plants, three experimental coal-hydrogenation pilot plants of about 10 gallons a day capacity, and laboratory-scale research apparatus for process development on both the coal-hydrogenation and gas-synthesis processes.

In order that no time should be lost while these new facilities were being designed and built, 5,000 square feet of additional laboratory and office space was obtained at the central experiment station of the Bureau of Mines in Pittsburgh, Pa., by building a mezzanine floor in a building designed to house mine rescue cars. With this additional space and with the securing of other temporarily available space it was possible to increase the research staff from 35 to 100 during 1945.

Synthesis Gas Production Division

Both hydrogen and carbon monoxide gases are used in making oil and gasoline from coal. The Synthesis Gas Production Division is developing the most economic methods for producing these gases from coal and lignite. This work is being conducted at Morgantown, W. Va., where the University of West Virginia, through a cooperative agreement with the Bureau of Mines, is providing laboratory and office space.

The work to be carried out by the Synthesis Gas Production Division includes the preparation and testing of fuels and the design, installation, and operation of adequate gas-making, gas-purifying, and gas-handling equipment. Through the use of existing information and by means of laboratory and pilot plant scale research, it is expected that finished gas can be made at lower than present cost.

DEMONSTRATION PLANTS

To enable the Government to furnish industry with the necessary cost and engineering data for the development of a synthetic liquid fuels industry, demonstration plants were planned for oil-shale distillation, coal-hydrogenation, and gas-synthesis processes. New equipment and methods devised in the research and development program can thus be tested on a larger scale and their feasibility and costs determined. Each of these plants will produce about 200 barrels of oil per day as compared to pilot-plant yields of 1 to 2 barrels per day.

Hydrogenation Demonstration Plant Division

To select the site for the coal demonstration plants an extended study was made which included a survey of 206 proposed locations in 21 coal-producing States. After the end of the war it became apparent, however, that some of the Government-owned synthetic ammonia plants used in the production of munitions would be closed down, and that they would offer an ideal location for the demonstration plant work. The War Department, acting through the Quartermaster General, has made the synthetic ammonia plant at Louisana, Mo., available to the Bureau of Mines. The Quartermaster General has a direct interest in the results of the Bureau's studies because he is responsible for the developmeent and procurement of natural and synthetic fuels and lubricants essential to national defense. The acquisition of the plant will result in a material saving in construction costs and will greatly speed the demonstration plant program. General facilities, such as offices, laboratories, boiler and power plant, water and sewage disposal system, machine shop, railroad spurs, coal-handling and storage facilities, roads and parking lots, and cafeteria are available for immediate use. In addition, specialized equipment, such as gas-cracking units, gas purifiers, compressors, and circulators, will be incorporated as part of the demonstration plant.

Preliminary flow diagrams and plot plans were started in 1945 for the erection of the coal-hydrogenation plant at Louisiana, Mo. Initial design is based on about 200 barrels of oil per day.

Gas Synthesis Demonstration Plant Division

The gas synthesis demonstration plant will also be at Louisana, Mo. Enginearing work for this plan is only in the initial stages and will not be completed until further information is available from the Research and Develop-

ment Division at Pittsburgh and Bruceton, Pa., for the most suitable converter design. The possibilities for improvement in this unit of the plant are so marked that it is desirable to have further results before construction of the gas synthesis demonstration plant is undertaken.

EUROPEAN OIL MISSION AND UTILIZATION OF INFORMATION OBTAINED

The two principal processes for producing synthetic liquid fuels from coal were developed in Germany and that country reached a peak production estimated at 40,000,000 barrels a year of synthetic oil and gasoline before Allied bombings reached the stage where their destruction exceeded German construction and repair efforts. Before the war, Germany gave little encouragement to the processing of oil shale, but when efforts to seize Caucasian oil fields had failed and the Rumanian refiners were bomber, an attempt was made further to develop oil-shale plants taken over in Estonia. After the Russians took over the Estonian plants, Germany worked feverishly to utilize the low-grade oil shale of Wurttemberg.

Details of new developments in Germany and the occupied countries since the beginning of the war were not available to American technicians until our victories in Europe provided an opportunity to visit the famous German synthetic-oil plants.

To obtain these details a technical oil mission was organized. Authorization for this project was contained in a letter, dated October 17, 1944, to Hon. Harold L. Ickes, Petroleum Administrator for War, from Admiral William D. Leahy for the Joint Chiefs of Staff.

Men for the mission were provided by the Bureau of Mines and the Petroleum Administration for War. Dr. W. C. Schroeder, Chief of the Office of Synthetic Liquid Fuels, was field leader of the group, which was composed of the following technologists:

Bureau of Mines representatives: Lester L. Hirst, Irvin H. Jones, Louis L. Newman, William W. Odell, Alfred R. Powell, W. C. Schroeder, Guenther von Elbe, Edward J. Rogers, Peter W. Sherwood.

Petroleum Administration for War representatives: John G. Allen, Harold V. Atwell, E. L. Baldeschweiler, George S. Bays, Ernest Cotton, L. P. Evans, Warren F. Faragher, Donaid S. Fraser, Vladimir Haensel, William A. Horne, Jean P. Jones, Paul K. Kuhne, Byron H. MacKusick, M. R. Mandelbaum, Hans Schnider, Ernest F. Voss, Horace M. Weir, E. B. Peck, and Earl Opal (London representative).

Following closely behind the armies, oil teams composed of these men and British experts examined what remained of the badly bombed German plants, collected records and research documents, interrogated operating and research personnel, and sent back samples for examination in our laboratories.

These investigators found that some important new developments had been incorporated in the large German plants especially in refining motor fuels and in converting the primary products to a variety of necessary materials such as lubricants, fats, soap, and margarine. However, a tremendous amount of research and development work had been done on improved processes which had never been put into commercial operation because of the pressing demand for oil and gasoline for war which prevented shutting down the plants long enough to make the necessary changes. In some cases new plants were bombed out before they could be put into operation.

The location and seizure of a great volume of German research documents is probably the most important achievement of the oil mission. Numerous plant operating records and reports, drawings, and flow sheets were also obtained.

Members of the oil team also had an opportunity to visit French oil-shale plants where information on new developments in processing oil shale was obtained.

Valuable reports were contributed by Navy technical groups which also conducted investigations of various phases of the European synthetic oil industry, especially the oil-shale industry.

The large volume of documents obtained was screened to eliminate unimportant material and the remainder microfilmed for transmission to this country. About 200 microfilms, each one covering about 1,000 pages of German material, had been received by the end of 1945. The Bureau of Mines set up a Foreign Synthetic Liquid Fuels Section to handle the work of translating and abstracting the material and the preparation of final reports which will be published.

To the extent that European processes are applicable to American coal, lignite, or oil shale, the information will be used to speed up the Bureau of Mines pro-

gram. Even though the nature of some of the European fuels is somewhat different from those in our country, many features of German technique and experience will be helpful in developing suitable processes for our raw materials.

(*b*) *Accomplishments in synthetic liquid fuels during the national defense and war periods.*

1. A survey of coals from various United States producing fields was made and yields and ease of liquefaction determined.
2. The character of the products and chemical byproduct yields from various types of United States coals were determined.
3. Following approval of Public Law 290 in 1944, the Office of Synthetic Liquid Fuels was organized and staffed. At the end of 1945 a force of 280 had been assembled.
4. Further development of a process for the production of a heavy bunker "C" type fuel oil by hydrogenation of coal in the experimental plant operating 24 hours a day for extended periods of time. The objective is to determine the minimum amount of hydrogen and the maximum throughout attainable.
5. Laboratory-scale development of a very efficient gas synthesis converted for which only about 10 percent of the steel required by the German converters is needed.
6. About 100 catalysts were tested for activity. For these tests a battery of 12 laboratory-size converters had been built and operated 24 hours a day for extended periods of time. Some catalysts were kept on "on stream" for 3 to 8 months to measure the rate of deterioration in activity. A number of physical characteristics, namely, X-ray diffraction patterns, surface areas, and magnetic properties, of catalysts were measured and correlated with the catalytic activity in the synthesis.
7. An exhaustive survey of technical and patent literature on synthetic liquid fuel processes was made.
8. Plans were drawn up and construction started on the laboratory and pilot-plant buildings at Bruceton, Pa., and at Laramie, Wyo. Pending completion of the construction work, research was conducted in temporary quarters and substantial progress made.
9. Following a careful study of a number of locations, the site for the oil-shale demonstration plant on the naval oil-shale reserves near Rifle, Colo., was selected and construction of the mine and plant started. The mine-haulage tunnel had been driven in 500 feet by the end of 1945.
10. An extensive site survey was made in which 206 proposed locations were considered for the coal-hydrogenation and gas-synthesis demonstration plants. A Government-owned synthetic-ammonia plant made available by the War Department was selected.
11. The Bureau cooperated in producing a quantity of shale oil required by the Navy for experimental work and conducted exhaustive tests on the oil obtained.
12. A core-drilling program at the oil-shale mine site was started. This was a cooperative effort with the Navy Department and the Geological Survey.
13. Some progress was made on the design of the coal-hydrogenation demonstration plant.
14. Several members of the Bureau staff took an active part in examining German synthetic-oil plants as soon as they were captured and in gathering detailed information on the German processes and research work that the Germans had been unable to put into practice.
15. A Foreign Synthetic Liquid Fuels Division was established to handle the enormous amount of information obtained.

(*c*) *Activities in synthetic liquid fuels that should be conducted to comply with the mandate in Public Law 520 (Strategic and Critical Materials Stock Piling Act of July 23, 1946)*

1. The Bureau of Mines synthetic liquid-fuels program authorized by Public Law 290 (78th Cong.) should be continued by amending that act to extend the time beyond the original 5-year period and to authorize the appropriation of additional funds. Two identical bills, S. 134 and H. R. 2161, have been introduced in the present session of Congress to effect this.
2. Our coal and oil-shale deposits must be depended upon to supplement our petroleum supplies as they are used up. Available information on these deposits is inadequate. Surveys should be made to determine more accurately the extent, quality, and mineability of these solid-fuel reserves that would be available for large-scale production of synthetic liquid fuels.

3. It is essential from the national defense viewpoint that synthetic liquid fuels be produced with a minimum of manpower. Therefore, mining methods, especially strip-mining methods, for coal and oil shale for synthetic liquid-fuel production should be investigated and improved methods developed.

4. Using German methods for the production of any important segment of our oil requirements from solid fuels would require an enormous amount of steel for plant construction and a large operating force, in addition to miners. While progress made in this country has already appreciably reduced these requirements, their present magnitude justifies special engineering research projects aimed at the reduction in equipment and labor requirements for synthetic liquid-fuel production. These studies would, of course, contribute to lower production costs.

5. Many of the chemicals that were critical items during the war, such as tar acids for plastic manufacture, and benzine, toluol, and xylol for explosives and solvents, can be produced as byproducts of the manufacture of synthetic liquid fuels. The yields from coal hydrogenation are about 10 times as high as those obtained in coal carbonization. There should be undertaken both technical and economic studies of these and other important chemicals obtainable in the manufacture of synthetic fuels.

6. Synthetic liquid fuels from coal and oil shale are not identical with gasolines, Diesel oils, and other fuels as ordinarily produced from petroleum. For some uses they are definitely superior and for others inferior. For example, coal hydrogenation motor fuel has excellent rich-mixture characteristics desired in aviation fuel, and Diesel oil from the gas-synthesis process is much superior to that used by our Navy. The adaptability of synthetic products to various uses should be fully investigated.

7. As a part of the preparedness for the commercial production of synthetic liquid fuels, which may become necessary for national defense, the Bureau of Mines, with the cooperation of private engineering firms, should make detailed project studies for large-scale plants to produce liquid fuels from: (*a*) oil shale; (*b*) coal; (*c*) lignite.

These studies should include plant-site requirements, accurate estimates of investment and operating costs, and all other information that private industry needs to reach a decision as to practicability of erecting the plants.

Senator O'MAHONEY. I think the same question ought to be addressed to Dr. Wrather.

Dr. WRATHER. Yes, sir.

If I may say a word about that, Senator, in response to your question, the work contemplated by the Stock-Piling Act is merged into our general Geological Survey program. Since the end of the war we no longer carry the classification of strategic and critical minerals as a separate item.

The whole mineral field is merged into one program because as you remember, at the cessation of the war, the strategic and critical minerals item was deleted.

Senator O'MAHONEY. I am aware it was transferred from the Bureau of Mines to the Geological Survey—certain types of work like the surveys to determine the location of particular minerals.

Now, can you tell us something about that program?

Dr. WRATHER. Dr. Bradley, Chief Geologist of the Geologic Branch, could give you more specific answers, but I think it might be well for us to prepare a statement on this item rather than trust to the material we have immediately at hand.

Senator O'MAHONEY. I think it ought to be done, because when you come before the Appropriations Committee, I am going to ask you to do the same thing there.

Mr. Chairman, the budget recommendation for the Geological Survey was something in excess of $18,000,000 to carry out this very necessary work for mineral development and search for new deposits, the mapping and the rest of it, including the surface water studies and the gaging of streams. But, that appropriation came to the Senate

from the House only a little over $9,000,000 with the specific statement, in various parts of the House report, that the activities of the Interior Department ought to be returned to the level of prewar days which, of course, is a thing that should not possibly be done if we are to carry out the program of the Stock-Piling Act and bring about the development of these resources which are so essential to our future.

Senator MALONE. I agree with you, Senator, that the American people through their Congress must make a decisión as to what course they will pursue.

Did you have anything further, Dr. Sayers?

Dr. SAYERS. Nothing further, thank you.

Senator MALONE. Then, I would like to call Mr. Ralston at this point, holding in abeyance the other witnesses that will be very important in this record—Mr. Pehrson and Mr. Bannerman.

The reason for calling Mr. Ralston, Oliver Ralston, is to follow the line of thought that you started in your own testimony, if that would be satisfactory to you, Doctor.

Dr. SAYERS. Yes.

(The prepared statement of Dr. Sayers is as follows:)

STATEMENT OF DR. R. R. SAYERS, DIRECTOR, BUREAU OF MINES

The Bureau of Mines was established in the Department of the Interior by an act of Congress approved May 16, 1910, to promote safety in the mineral industries, conserve mineral resources, and to conduct investigations on the mining, preparation, and use of minerals. In 1925, the Bureau transferred to the Department of Commerce, and returned to the Department of the Interior in 1934.

Since its creation, the Bureau has pursued numerous activities related to the basic functions of the act. It has introduced new safety practices, improved techniques of using minerals, and published much scientific, technical, and economic information vital to the progress of the mineral industries.

Section 2 of the amended act (37 Stat. 681) stipulates that the province and duties of the Bureau shall be "to conduct inquiries and scientific and technologic investigations concerning mining, and the preparation, treatment, and utilization of mineral substances with a view to improving health conditions, and increasing safety, efficiency, economic development, and conserving resources through the prevention of waste in the mining, quarrying, metallurgical, and other mineral industries; to inquire into the economic conditions affecting these industries; to investigate explosives and peat; and on behalf of the Government to investigate the mineral fuels and unfinished mineral products belonging to, or for the use of, the United States, with a view to their most efficient mining, preparation, treatment, and use; and to disseminate information concerning these subjects in such a manner as will best carry out the purpose of the act."

Section 3 provides:

"That the director of said Bureau shall prepare and publish, subject to the direction of the Secretary of the Interior, under the appropriations made from time to time by Congress, reports of inquiries and investigations, with appropriate recommendations of the Bureau, concerning the nature, causes, and prevention of accidents, and the improvement of conditions, methods, and equipment, with special reference to health, safety, and prevention of waste in the mining, quarrying, metallurgical, and other mineral industries; and the use of explosives, and electricity, safety methods and appliances, and rescue and first-aid work in said industries; the causes and prevention of mine fires; and other subjects included under the provisions of this act."

Section 4 forbids any member of the Bureau staff to have any personal or private interest in any mine or the products of any mine under investigation, or to accept employment from any private party for services in the examination of any mine or private mineral property, or to issue any report as to the valuation or the management of any mine or other private mineral property.

At first the Bureau gave attention chiefly to investigations of causes and remedies for accidents, especially coal-mine explosions, and to the testing of fuels, its work thus relating largely to coal and coal mining. In response to a general

demand that the Bureau conduct further investigations in other branches of the mineral industries, Congress, by an act approved February 25, 1913 (37 Stat. 681), designated the Bureau as "a bureau of mining, metallurgy, and mineral technology."

These organic functions of the Bureau were supplemented by the Foster Act of March 3, 1915, which authorized the establishment and maintenance of mining experiment stations and mine safety stations in important mining regions to conduct investigations and disseminate information in accordance with the act establishing the Bureau, and empowered the Secretary of the Interior to accept lands, buildings, or other contributions from the several States offering to cooperate in carrying out the purposes of the act.

By virtue of an act approved March 3, 1925, and amended March 3, 1927, the Bureau of Mines is the sole agency entrusted with the production of helium for Government use, including the acquisition of gas lands, drilling of wells, construction of plants and pipe lines, and all other necessary operations. A further amendment, approved September 1, 1937, authorized the commercial sale of helium gas by the Bureau.

Other functions have been delegated to the Bureau from time to time by special legislation. The War Explosives Act of October 6, 1917, as amended December 26, 1941, provides for the licensing by the Director of the Bureau of Mines of the manufacture and sale of explosives in time of war. The explorations carried out under the Potash Act of June 25, 1926, disclosed such extensive deposits that the Nation is no longer dependent on foreign sources of potash supply as it was at the time of the First World War. The Strategic Materials Act of June 7, 1939, authorizes investigation of possible domestic sources of strategic minerals.

The act of May 7, 1941, empowers the Bureau to enter and inspect coal mines for the purpose of obtaining the information necessary to improve the operation of mines with respect to the health and safety of the miners.

Public Law 290, approved April 5, 1944, authorizes the construction and operation of demonstration plants to produce synthetic liquid fuels from coal, oil shale, agricultural and forestry products, and other substances.

The Bureau of Mines has as its major objective the promotion of safety in the mineral industries, the conservation of mineral resources and the conducting of investigations on the mining, preparation and utilization of minerals. These ends are sought through the development and introduction of safe practices and improvements in the techniques of winning and utilizing mineral substances. Scientific, technical, and economic studies in laboratory, office, and field have yielded basic information that has contributed notably to the progress of the industry.

The Health and Safety Branch, which consists of three divisions, investigates conditions affecting the health and safety of workers in the mining, metallurgical, and allied industries.

The Safety Division makes investigations of health and safety conditions in and around mining operations and in the field instructs mine officials and workmen in safety measures, accident-prevention methods, and mine rescue and recovery operations. It teaches first aid to allevate the effects of accidental injury. In an endeavor to comply with the requests of the mining industries, the Division has emphasized training activities; more than 1,600,000 first-aid and mine rescue courses have been given since the initation of the work in 1910, including 1,152,000 in the coal-mining industry alone. The Division operates safety stations at Albany, N. Y.; Dallas, Tex.; Denver, Colo.; Birmingham, Ala.; Duluth, Minn; Jellico, Tenn.; Juneau, Alaska; McAlester, Okla.; Norton, Va.; Phoenix, Ariz.; Pittsburgh, Pa.; Salt Lake City, Utah; Berkeley, Calif.; Seattle, Wash.; Vincennes, Ind.; and Wilkes-Barre, Pa.; mine rescue-car headquarters at Anchorage, Alaska; and field offices at Bartlesville, Okla., and Houston, Tex.

The Health Division seeks to identify health hazards and devise means to eliminate or minimize them. Among the problems being studied are the effect of working environment on human well-being, the efficacy and suitability of respiratory devices, and the harmful effect of industrial dusts and toxic gases in and around mines and metallurgical plants and the alleviation measures available. The work is being done in the field as well as in the laboratory and in cooperation with the Public Health Service.

The Coal Mine Inspection Division created in 1941 by the act of May 7, 1941, authorizing the Bureau of Mines to make and to publish the results of coal mine inspections throughout the United States is now the largest division of the Health and Safety Branch. Its members are now making approximately 3,500 coal mine inspections per year and giving the results of these inspections of individual

mines to the public. In addition, numerous investigations are made with respect to matters pertaining to the use of electricity, explosives, etc., which affect health or safety or both health and safety in coal mining. During the fiscal year 1947 the Coal Mine Inspection Division cooperated with the Coal Mines Administration in promoting and maintaining safety in the coal mines which were in possession of the Government.

The Fuels and Explosives Branch is divided into the Coal Division, the Division of Petroleum and Natural Gas, the Explosives Division, the Fuels Utilization Division, and the Office of Synthetic Liquid Fuels. The Branch is responsible for scientific research and technologic investigations pertaining to coal, petroleum, natural gas, and their products, and explosives, with particular reference to the conservation and most efficient utilization of mineral fuel resources.

The Coal Division conducts scientific research and engineering investigations and tests on the chemical and physical properties of coal, and on the mining, preparation, combustion, carbonization, and gasification of coal. This work includes chemical and petrographic analysis of coals, investigation of coal deposits, studies of mining methods and costs, washing and preparation of coal for general and special purposes, research on the burning of coal in industrial and domestic furnaces, and research and tests on the making of coke, gas, tar, and byproducts. Most of this work is done at the Pittsburgh Experiment Station. Research laboratories and a pilot plant studying the drying and gasification of subbituminous coal and lignits are located at Golden, Colo., and Grand Forks, N. Dak.

The Petroleum and Natural Gas Division conducts fundamental technical research and field and pilot-plant tests relating to the production, storage, transportation, and refining of petroleum, natural gas, and their derivatives, with the view of reducing waste, increasing efficiency, and developing bettter methods and products; and supplies technical information concerning these subjects to Government agencies, industry, and the public. Its largest centers are at Laramie, Wyo., and Bartlesville, Okla. Laboratory studies are also conducted at the Dallas, Tex.; San Francisco, Calif.; and Franklin, Pa.; field offices, as well as in oil and gas fields and refineries. The Division also operates and maintains helium-bearing gas fields in Potter County, Tex., and San Juan County, N. Mex., and helium plants at Amarillo and Exell, Tex.; Otis, Kans.; and Shiprock, N. Mex.

The Office of Synthetic Liquid Fuels conducts research and development work on the production of motor fuels and other products from coal, lignite, and oil shale. The work on coal is centered at Pittsburgh and Bruceton, Pa. A laboratory, dealing with the production of synthesis gas and hydrogen for use in making synthetic liquid fuels, is at Morgantown, W. Va. The research on oil shale is conducted at Laramie, Wyo. All of this work is directed toward the development of fundamental information for the design, erection, and operation of synthetic liquid fuels demonstration plants. The demonstration plants using coal and lignite as raw material are at Louisiana, Mo. The oil-shale demonstration plant is at Rifle, Colo., and includes both the extraction plant and the oil-shale mining operations. The ultimate aim of all this program is to furnish private industry costs and engineering data that will be needed in developing a synthetic liquid fuel industry, and thereby increasing the Nation's oil reserves.

The Explosives Division conducts fundamental scientific research and tests on industrial and propellant explosives and on development of new explosive mixtures; investigates causes of disastrous explosions and devises methods for the prevention of explosions; conducts research and development work and tests on sheaths and methods of sheathing explosives, and on detonators and primers; conducts tests on explosives and blasting devices to determine their permissibility for use in coal mines or suitability for use in other mining operations, and to determine size of charges for such use; conducts research and tests on the explosibility and flammability of gases and vapors, the ignition of explosive mine atmospheres, and the contamination of mine atmospheres by gases from explosives; determines the flammability and explosibility of coal, mineral, other industrial dusts and develops methods for preventing dust explosions; develops special equipment for physical tests, and maintains and calibrates tests equipment and instruments; and cooperates with industry, and associations and scientific groups in the development of safer explosives and of safe procedures to minimize and eliminate disasters. Its work is conducted principally at Pittsburgh and Bruceton, Pa.

The Fuels Utilization Division conducts technologic and engineering studies and tests relating to the inspection and utilization of fuels and the operation and maintenance of fuel-bearing equipment in the most efficient and economical

manner; provides assistance and consulting service to Government agencies on problems relating to the purchase and most efficient use of fuels, the storage of coal, and purchase, operation, and maintenance of fuel-burning equipment, including boiler-water treatment; and provides information to Government agencies, industry, and the public on smoke abatement and the conservation and substitution of fuels. The laboratory work is centered at the College Park (Md.) Experiment Station.

The Mining Branch conducts engineering examinations of mineral deposits that appear from preliminary evidence to warrant investigation from the national viewpoint; develops and samples those deposits that examination work indicates to be of sufficient interest; studies labor-saving and money-saving innovations in mining and milling methods; investigates the state of the mineral industry and its future possibilities in individual mining districts; conducts experimental work on development methods and on mining methods; and experimentally mines, with application of innovations, parts of typical deposits in order to demonstrate the most effective methods of extracting hitherto unused ores from the ground. The operations of the Mining Branch in the field are conducted through divisional and field offices at Tuscaloosa, Ala.; Juneau, Alaska; Tucson, Ariz.; College Park, Md.; Minneapolis, Minn.; Rolla, Mo.; Reno, Nev.; Raleigh, N. C.; Albany, Oreg.; Salt Lake City, Utah; Spokane, Wash.; Helena, Mont.; San Francisco, Calif.; Denver, Colo.; Rapid City, S. Dak.; Silver City, N. Mex.; and Austin, Tex. An experimental mine in hard rock is operated at Mount Weather, Va.

The Metallurgical Branch develops processes for ores that do not respond to routine beneficiation methods, new techniques, and special equipment which are evaluated in its pilot plants. The results of laboratory and pilot-plant tests are made available to industry as new metallurgical methods.

It is often necessary to show that the improved metals thus obtained are acceptable to the manufacturers of metals and alloys. This work includes new technology of iron and steel production as carried out at Redding, Calif.; Rolla, Mo.; Raleigh, N. C.; Boulder City, Nev.; Laramie, Wyo.; and other locations. Raw materials found in the Pacific Northwest, such as iron-chromium-nickel ores, are under development by the Bureau, the process being carried through from ore to finished product. The making of sponge iron directly from the ore is another process which has been highly developed by the Bureau of Mines. Work also is being carried out on the production and uses of light metals, including titanium, recently obtained by the Bureau in ductile form. The development of production methods for the rarer metals, such as vanadium, zirconium, and cobalt is in progress. Problems in nonferrous metal technology are being investigated. The refining of waste metals from airplane manufacture, also being worked on by the Metallurgical Branch, is a particularly live subject. Work on nonmetallic minerals is being carried on at Norris, Tenn.; Tuscaloosa, Ala.; and Seattle, Wash.

In addition to this development work, the Metallurgical Branch also carries out the analysis and testing of thousands of ore samples submitted to its experiment stations located in the principal mineral-bearing areas of the United States.

The Economics and Statistics Branch studies economic problems of the mineral industry, prepares analytical reports thereon for public and Government use, and compiles and publishes statistics on sources, production, consumption, distribution, stocks, prices, employment, mine accidents, and other related factors in all branches of the mineral industries. These services provide data essential to the planning and conduct of industry and Government operations and also are essential to the efficient planning of the Bureau's program in technologic research, exploration, and the promotion of health and safety in the mineral industries. Many weekly, monthly, annual, and special reports are published each year and these are widely used by industry and the public. Minerals Yearbook, and its predecessor, Mineral Resources of the United States, has been published annually since 1882 and its enjoys world-wide recognition as an outstanding authoritative reference. The Branch activity is directed primarily to domestic industries, but a substantial fact-finding service on foreign minerals is maintained to assist domestic producers seeking foreign markets for their products, domestic consumers requiring foreign raw materials, and Government agencies concerned with the country's international economic relations.

Field offices are maintained at Denver, Colo.; Joplin, Mo.; Salt Lake City, Utah; Los Angeles and San Francisco, Calif.; Pittsburgh, Pa.; and College Park, Md.

All of the pertinent data in these branches of the Bureau were made available in the preparation of the report on the mineral position of the United States which Secretary Krug submitted to your committee this morning. The report was prepared under the supervision of E. W. Pehrson, of the Bureau of Mines, and H. M. Bannerman, of the Geological Survey. Mr. Pehrson and Mr. Bannerman are here this morning and will be glad to discuss the report, if the committee desires.

Senator MALONE. Mr. Ralston.

Mr. Ralston, you heard the testimony of Dr. Sayers in relation to the experiments that have been carried on, metallurgical experiments and pilot-plant work.

I know personally of your work. I think it is unnecessary to ask you specific questions. I would only ask you to cover in general the field of your work and specifically these materials upon which the work has been carried forward, together with its status.

STATEMENT OF OLIVER C. RALSTON, CHIEF OF THE METALLURGICAL BRANCH, BUREAU OF MINES, DEPARTMENT OF THE INTERIOR

Mr. RALSTON. I have the Branch of Metallurgy and Minerals, new mineral technology, of the Bureau of Mines.

During the war, we had a greatly accelerated program, and practically every essential mineral had to be involved in such a program because at one time or another there was a shortage either of supply or of production capacity, and questions of conservation, substitutions, all through the line had to be studied.

What you were referring to was Dr. Sayers' mentioning pilot-plant activities; was that what you wanted?

Senator MALONE. In both directions, Mr. Ralston; both in your laboratory and metallurgical experiments, that open up greater fields for use of these minerals and also then on the economic side, the pilot plant to test feasibility or to determine feasibility.

Mr. RALSTON. Almost any activity that we work on is something that industry must utilize. We start work frequently in what you might call a laboratory test-tube scale. We work up to a wheelbarrowfull at a time and little test plants and ultimately there are things that must be proven in machinery or components of near industrial size or in what we call pilot plants.

A pilot plant is a bigger thing than a little test plant.

Senator MALONE. You might, at this point, for the information of the committee tell us what generally is considered the proper size for a pilot plant, and what do they generally cost in your work?

Mr. RALSTON. They would vary with the material. For a thing like beryllium, which is not worked in large quantities, a pilot plant might be something that would treat 100 pounds in a day.

In the case of iron and steel, it might be regarded as a toy when it was 50 tons a day.

They usually cost more than the equivalent industrial plants because you must have a great many alternate pieces of equipment to work with. If one does not work well, you have to substitute another. They should invariably have a contingency fund to make those changes as the material itself tells you whether it will work willingly or it will not.

So, the cost of pilot plants is usually much greater than if you were just setting up a plant to produce by one definite method.

With pilot plants, while you have learned a great deal by your previous study, there are still many unknown factors that must be taken care of. That is the reason for their high cost.

Dr. Sayers mentioned that we have had pilot plants constructed in this country that have not yet operated. That was true, especially of these alumina plants, which he listed. The one in Oregon was in Salem so you can complete his record by adding Salem, Oreg. The others were at Laramie, Wyo.; Salt Lake City, Utah; Harleyville, S. C.

The one at Salt Lake City was the only one that really had a good shake-down run. The other three have had practically no operation. They have turned over to a certain extent, met the first difficulties in the case of Harleyville, S. C., and then knew how they should revamp in order to have a chance of a better run.

Senator MALONE. Mr. Ralston, for the benefit of the committee, some of the members are not here, what would it mean if these pilot plants were successful? That is, is it not a fact that our bauxite reserves from which raw material for the manufacture of aluminum is customarily secured are rather short and that if these pilot plants were to be successful economically, would it not open up a great deal of raw material in this country?

Mr. RALSTON. That is correct. That is a very good point.

Senator MALONE. That is the very purpose of the pilot plant.

Mr. RALSTON. That was the purpose because of shortage of bauxite supply. Our normal supply of aluminum is from imported bauxite.

Now, a good deal of our own is used——

Senator MALONE (interposing). As a matter of fact, we could become self-sufficient if all these experiments worked out properly.

Mr. RALSTON. As a security measure it is very important. If we have to produce aluminum in another emergency like the past one, we are going to have to produce it from our local materials, the clays or the alunite or the anorthosite, that contain rather high proportions of aluminum oxide.

Senator MALONE. Where do we get our bauxite outside of this country?

Mr. RALSTON. We did operate our aluminum industry entirely in the early days on Arkansas bauxite and we still do use Arkansas bauxite.

Senator MALONE. I mean if we had to import it?

Mr. RALSTON. The supply of metallurgical grade is not satisfactory there and the Arkansas bauxite has other uses, chemical, abrasive, and so on. It is better bauxite for most of these other purposes than most of the imported.

So, we rely now mainly on imported bauxite for aluminum metal production. We do have minor deposits in some other States.

Senator MALONE. Where do we get the imported supply?

Mr. RALSTON. The imported material comes from the north coast of South America. Dutch Guiana, some from British Guiana, and practically none from French Guiana, although it is in all three of those places.

Senator MALONE. The point I make is that in case of another war it can become embarrasing and dangerous to this country in trying to import this material in time of war?

Mr. RALSTON. That is so. We were decidedly embarrassed along at the beginning of 1943 when, of the 60 ore "boats" that were bringing aluminum ore from the north coast of South America to the United States, we reached a point where 52 out of the 60 had been sunk. No one dared to breathe the situation at the time to the people or, more important, to the enemy. It was a large amount. And, we went through the rest of the war with ships that were substituted, not well built for that purpose. The special ore ships were prepared for fast loading and unloading. So, we fought the war with substitute ships.

Senator MALONE. The point, then, is that the operation of these pilot plants, if we could become successful in securing local material, would be worth whatever it cost.

Mr. RALSTON. Yes. It does seem poor economy to spend the money in building such pilot plants, and then decide that we are returning to a prewar economy and that it is not necessary to finish up the work in those plants.

Now, the same is true of the pilot plants built by the Bureau of Mines. We have some that we can stop. We can call an end point at the present time. But, the list that we have put in as a result of the House action on our budget here, and the list of 12 plants, and not all of those by any means should be stopped at this time——

Senator MALONE (interposing). Would you at this point, Mr. Ralston, give us a list of the plants that, in your opinion, are in the category of the alumina plants, and just in round figures what it would cost to operate them for another year?

Mr. RALSTON. Each of those three alumina plants that have not been operated has a capacity of 50 tons per day, and it is my memory we calculated roughly a million dollars apiece to see them through a year's operation, if there were no sale of finished products.

If they were so operated that you could sell finished products and not send the check to the Treasury to be reappropriated some other year, you could have a revolving fund, you might say, from the sale of material that would not require such large amounts of money.

The pilot plants in the Bureau of Mines are operated without benefit of the sale of any products. That is the regular governmental procedure. Any sale of material goes into miscellaneous receipts of the Treasury.

Due to the fact that we usually get less money for pilot plants than we ask for and than we think is necessary, that is embarrassing. We could actually do more for less money if we were allowed to sell and reuse the money. But still, Government would then be in business and that is a policy which is not entirely appropriate. So that we do not sell material.

Senator MALONE. Well, that money nevertheless does revert to the Treasury and should be taken into account when the entire story is told.

Mr. RALSTON. We have substituted another policy. In the case of the electrolytic manganese where we had a 1-ton-a-day pilot plant we accumulated quite a stock pile and then decided it should be busy during the war. Manganese in many alloys where there is no carbon fulfills the functions of nickel, so to one of the stainless-steel plants not

getting all the nickel it wanted, we proposed to make a shipment of a carload to see if they could substitute manganese in whole or in part for nickel. They had made preliminary experiments and were willing to make a test.

We gave them the material on the stipulation that they actually try it out, actually make finished products and get them into industry and see how well they acted, and we would get the reports. They were taking quite a risk, and so we did not ask for any compensation for that. There was plenty of risk on their part.

The manganese-bearing stainless got into the market. The other stainless companies found that it was good. They all wanted some. So, they began cleaning up our stock pile of electrolytic manganese, and it all went into not only stainless steel but other places where nickel otherwise goes.

Senator MALONE. But, it did replace a supply of nickel otherwise necessary?

Mr. RALSTON. Yes, that is right.

Senator MALONE. And, as a matter of fact, we produce very little, if any, native nickel?

Mr. RALSTON. Yes. It resulted in orders from one existing producer who had started on a scale where he could make no money but he had to do the missionary work of finding users. It gave him enough users that he doubled his plant, and then he redoubled it, and then he re-redoubled it, and he got his production costs down below the price of nickel.

I should say that he has passed the infant-industry stage already, and many years before he normally would have been out of it. We are following that now on titanium. Titanium, as Dr. Sayers indicated, is the fourth most plentiful metal in the earth's crust that withstands action of air and can be used for structural purposes. It is exceeded by aluminum first, iron, then magnesium. It has not been used in the past. There are great difficulties in extracting it. It is always going to cost more.

We find it is really worth more than the other structural metals—that it is a wonderful metal. And, we are supplying limited amounts from our very small pilot plant to aggressive and progressive potential producers for their experiments, and the demand is growing so fast that with the necessity of cutting back funds for this coming year we actually have a demand for 10 times what we can make in this new industry.

Now, the significance of titanium is this: Without ever alloying it, without ever doing anything, just the straight titanium is these or four times as strong as any of the magnesium alloys, and it only weighs twice as much. So, we can actually substitute in airplane parts titanium parts of equal strength weighing only half what the magnesium parts do, and magnesium is the lightest metal which has been used in airplane construction.

And, comparing titanium with stainless steel, it will fulfill many of the uses of stainless steel. Stainless steel calls for 18 percent chromium, one of the strategics, and, say, 8 percent nickel, another strategic.

Titanium can thus substitute for stainless steel to the extent that titanium sheets and rods can be used in places where stainless has

been used. We do not have a good supply of the chromium and nickel for stainless in the United States. It is a very attractive thing.

Senator MALONE. At what stage is the development of titanium? Is the pilot plant necessary?

Mr. RALSTON. Yes. It hardly deserves the status of what we would call a pilot plant, because 100 pounds at a batch of such a structural metal would not let you construct an airplane except only once every 2 or 3 years. We really need to advance that to a much larger scale to call it a pilot plant.

Senator O'MAHONEY. How far before your research would stimulate the investment of private capital in the same picture?

Mr. RALSTON. I can answer that by stating a little ductile titanium was made 12 years ago by the Titanium Alloy & Manufacturing Co. in Niagara Falls. They used a method that gave them only 1 batch out of 10 that they could use. This was difficult. But, they had some metal suitable for sheet titanium that they rolled. One could ask for some and they would ask what you were going to do with it, and they would say, "Well, we will give you a small sample." They might trim off a 4-inch square, and what could you do with a 4-inch square after you got it?

In other words, they had a very tiny amount and they had not risked enough venture capital or anything else in pushing it. I do not know whether they have appreciation of the futility of moving so cautiously. They now ask us for the material made by our somewhat cheaper process, which gives reliable batches every time. At the present time, the Bureau of Mines is the principal source of ductile titanium for experimental purposes, and its pilot plant is much too small.

It is an industry that can roll up like a snowball if we give it the right impetus.

Senator O'MAHONEY. What needs to be done to give the impetus?

Mr. RALSTON. Money. We need money for expanding the plant.

Senator O'MAHONEY. In the Bureau?

Mr. RALSTON. In the Bureau. We should double or treble the producing plants. The physical metallurgists who are gathering the data on its behavior need to have more rolling, swaging, forging equipment.

Senator O'MAHONEY. What is the market for this? You have mentioned airplane parts. What other things?

Mr. RALSTRON. Of course, there is no established market. There are many potential users. But, we must grow on a scale just as fast as the interest grows. Normally, a commercial firm doing it would multiply just as fast as the interest grew. This year we are being cut back in funds, to get along on half of what we did before.

Senator O'MAHONEY. What are the deposits of titanium?

Mr. RALSTON. Titanium ores?

Senator O'MAHONEY. In the United States.

Mr. RALSTON. Senator O'Mahoney, while you have a very important deposit at Iron Mountain, Wyo., which is a nice large one, titanium is widespread. There are titanium minerals in heavy fractions of sand in nearly every stream. They are on the beaches. There are large areas of primary ore along the north shore of Lake Superior, all along the St. Lawrence.

There are comparable deposits to Iron Mountain in several other places in the United States. We have it along all borders and in nearly every State you can find a little workable titanium mineral.

Senator O'Mahoney. Are there sufficient supplies and sufficient utility to justify, first, the investment of Government funds to enable the Bureau of Mines to demonstrate the possibilities, and, secondly, to inspire the investment of private funds to develop an industry?

Mr. Ralston. That is really several questions. The supply, as I mentioned first, is the fourth most plentiful metal capable of structural use. There are, of course, other known chemical elements called metals that are not stable in air, and the only ones that are more plentiful I named.

So, the domestic supply is good. It is perfectly reliable. There is lots of it.

Senator Malone. In your opinion, Mr. Ralston, if you could continue your work, would it develop into a business?

Mr. Ralston. No doubt about it. It may be a metal that it would take us some years to get the cost of production down to as low as a dollar a pound. There are more difficulties than in making aluminum, now selling at 15 cents a pound.

Senator Malone. Where would it have to get in price before it would be generally utilized?

Mr. Ralston. I think there would be a great use of it at $5.

Senator Malone. Time is getting short. Both Senator O'Mahoney and myself will have to be on the Senate floor at 12 o'clock, and I do not want to rush your testimony if you have not finished it. We will continue at 10 o'clock in the morning. But I wondered if you could just briefly name over the field of experiments that you are engaged in that does have promise in new materials.

Mr. Ralston. Yes. A sister element to titanium is another metal called zirconium. It is much more resistant to corrosive influences than titanium, just as titanium and stainless steel are better than ordinary steel. It is almost a precious metal.

While its supply is not as large as titanium, we have large domestic sources of zirconium. It is something we do not have to depend on for import, though the first zirconium worked in this country was all imported material for some reason.

Besides that, we have at the present time new things that have just come up since the war that are of military importance. Thallium—which I cannot tell you about in an open meeting. That is new work, and it is going to give us better fighting forces, better tools in their hands.

We have unfinished business in magnesium. The carbothermic method of making magnesium was pushed to its largest scale in the Kaiser plant, but it was still a batch process. Ours is one capable of continuous use, and continuous processes ultimately nearly always turn out to be more economical than batch processes.

We are having to shut down a small magnesium unit at Pullman, Wash. We have a better unit built on Pullman's experience at Albany, Oreg., but we will have funds to operate it only half a year and then let it stand idle.

We have unfinished business in iron with the imminent exhaustion of the iron ores in the iron ranges in Minnesota. Something has to be done in advance all the way along the line in the whole iron and steel metallurgy.

We are having to shut down at Laramie, Wyo., our largest sponge-iron experiment there. There were no funds to run it during this present year except for a short time, and it is absolutely nonavailable for next year.

There are very important things to be done in nickel. We have a little nickel that we found during the war in the Northwest mainly and in ores that are not immediately amenable to present ways of doing things. We want to carry that on with greater impetus than we have done before.

Senator MALONE. The significance of that experimentation then is that we now produce practically no native nickel at all? Is that right?

Mr. RALSTON. That is right.

Senator MALONE. Therefore, we are dependent entirely on Canada and other sources for nickel?

Mr. RALSTON. Yes. We did discover during the war that we had several sources of cobalt, and we have a small cobalt plant at Boulder City, Nev., which should have been doubled this year, but it cannot be. We had only one commercial-size cell, and we felt we should go a little faster on that. It has dragged unduly.

Practically all of them that I mentioned are strategic.

Senator O'MAHONEY. I wonder if after this session is over if you could prepare a little statement showing the amount of investment in that new industry which you said has grown beyond the scope of an infant industry?

Mr. RALSTON. Yes.

Senator O'MAHONEY. As a result of the pioneer work of the Bureau of Mines.

Mr. RALSTON. Yes.

Senator O'MAHONEY. In other words, I want to make a comparison of the appropriations made by Congress to enable you to carry on that work and the products in private industry.

Mr. RALSTON. Yes.

Senator O'MAHONEY. And, if there are any similar comparisons that you could make I think it would be very valuable.

Mr. RALSTON. I think I can probably get from the operator whom we mentioned his investment for this purpose.

Senator MALONE. Senator O'Mahoney, I was going to suggest in view of the extreme importance of the work of Mr. Ralston—I happen to be rather familiar with his work because we have worked together at various times over the years—that he should prepare a rather comprehensive statement of the entire list in the field as covered by his work, showing the status and the relative importance to national defense and the strategic mineral field of substitutes for nickel like electrolytic manganese which is extremely important due to our practically having no nickel at all.

Mr. RALSTON. Do you want me to incorporate that as a part of Dr. Sayers' report?

Senator MALONE. I would like to have you prepare such a report, and take your time in doing it.

The committee must recess. We will recess until 10 o'clock tomorrow morning. Mr. Ralston, would you like to come back in the morning?

Mr. RALSTON. If I can help you in any way.

Senator MALONE. I would like you to do it. I would like to have you prepare such a statement. If that is not time enough, take your time.

There are four other important witnesses here this morning, but we would like to have them come back tomorrow morning. Mr. Elmer W. Pehrson, Chief, Economics and Statistical Branch, Bureau of Mines; Harold M. Bannerman, Chief, Division of Economic Geology; Wilmot H. Bradley, Chief Geologist of the Geology Branch; Tom Miller, Assistant Director of the Bureau of Mines. If they will return in the morning with Mr. Ralston we will appreciate it.

We will continue the hearing at 10 o'clock tomorrow morning.

(Whereupon, at 12 noon, the committee adjourned until 10 a. m., Friday, May 16, 1947.)

INVESTIGATION OF NATIONAL RESOURCES

FRIDAY, MAY 16, 1947

United States Senate,
Subcommittee on National Resources Economic
of the Committee on Public Lands,
Washington, D. C.

The subcommittee met, pursuant to adjournment, at 10:10 a. m., in room 224, Senate Office Building, Senator George W. Malone presiding.

Present: Senators Malone (presiding) and O'Mahoney.

Senator Malone. The committee will be in order.

Mr. Oliver Ralston has not completed his testimony and will proceed from where he left off.

STATEMENT OF OLIVER C. RALSTON—Resumed

Mr. Ralston. For the record, supplementing my testimony of yesterday, I have brought some samples of titanium for your inspection.

Senator Malone. This is the material that you testified was four times as strong and twice as heavy, making any object manufactured from it of the same strength half as heavy as the same thing manufactured in the same thing from magnesium; is that true?

Mr. Ralston. I was comparing magnesium. The ingot in Senator O'Mahoney's hand, you notice—he can hold it by one end. A steel ingot—he couldn't handle that in that manner.

Senator O'Mahoney. I can hold it by one end, but I can't bend it.

Mr. Ralston. Here is a piece of sheet that you can bend, Senator, and here is a personal sample, if you would wish it, and the chairman might wish one. This ⅜-inch rod will illustrate to you the light weight of the material. It is not much heavier than a lead pencil. The sister element that I also mentioned yesterday, zirconium, which is almost a precious metal in its behavior—I also thought you would like to see that. No one else is making ductile titanium except by processes that are prohibitively expensive.

Senator O'Mahoney. What is the capacity of these metals to stand or to revolve in a part? How long do they stand it? You spoke about airplane parts, for example. How long does it take them to get tired, in other words?

Mr. Ralston. Both are types that do not suffer fatigue as rapidly, for instance, as magnesium, which is very crystalline and which tends to be coarsely crystalline. Both of these metals burn easily. You can roll titanium in temperatures up to 600° centigrade or 1100° Fahrenheit in air, but any hotter it will burn.

Senator Malone. When you say "burn" you mean to become hardened and brittle?

Mr. RALSTON. It oxidizes.

Senator MALONE. But in speaking of burning it might be misunderstood, magnesium is more inflammable, is it not, than any of these materials?

Mr. RALSTON. The most inflammable metal powder is probably zirconium, but when it is melted into solid pieces it is difficult to ignite it and make it burn, or flame.

Senator MALONE. Isn't it much more difficult to burn zirconium than the magnesium metal and much less inflammable in a manufactured product like an airplane?

Mr. RALSTON. Well, in big pieces like this, the heat is conducted away so fast that it is hard to ignite. Zirconium powder will ignite spontaneously. It was used in photo flash bulbs for awhile, but if you happen to drop one and break it on the floor—one that has not been exploded—if it broke on the floor it would set fire to the carpet before you can brush it up. In this piece of lead there is a mixture of titanium and zirconium powders which as soon as you strike them, like striking a couple of flints together, gives considerable sparking [indicating]. That is the basis of a new sparking metal that came onto the market last month. It is going to ease the situation on cerium, which we get mainly out of monazite and also has thorium in it. Thorium is one of the fissionable metals, and therefore that source of supply is under the umbrella of the Atomic Energy Commission, and you are allowed to get it out only with great difficulty. The three cerium-producing companies in the country are having trouble to get their supply.

This is another of those substitutions that actually is not a "substitution"; it is an improvement. This sparking metal that I have just demonstrated to you gives about 10 times as hot a spark with the same size flint in an ordinary lighter. In other words, you don't have to twirl the little wheel on the lighter as many times to get a light.

Senator MALONE. What does it contain, Mr. Ralston?

Mr. RALSTON. This alloy is a matrix of lead which makes it soft. The lead has in it a mixture of powder of titanium and zirconium, one that is a slow spark and the other is too fast; the mixture has been adjusted to be better in the present cerium lighters, but still not to be too fast. Those are demonstrations aside from the testimony. I have brought the written material that you asked for yesterday.

Senator MALONE. It will be submitted for the record.

(Mr. Ralston submitted the material referred to as follows:)

SUPPLEMENTARY INFORMATION SUPPLIED BY O. C. RALSTON

The Metallurgical Branch of the Bureau of Mines finds its place in the program of development of the national resources in providing technologic methods for extracting metals and minerals from the low-grade and complex ores and minerals. The exploration work by the Geological Survey and by the Mining Branch of the Bureau of Mines does not always provide deposits of high-grade ores.

High-grade ores and minerals suitable for sale receive very little attention from the Bureau of Mines except as possible sources of rare minor metals or minerals that may be wasted.

Low-grade ores and complex ores soon become the main resources after the lush ores are gone. The many problems involved in such ores come to the Bureau of Mines for its attention in the interest of increasing efficiency in the mineral industries and prevention of waste. They are the ores of tomorrow.

The step from use by industry of the ores workable by today's technology

to the economically submarginal deposits is made possible by technological advances. I have seen three such steps take place in the copper industry during my career. Germany was out of high-grade iron ore long ago and was working ores regarded as submarginal by American standards. The United States is on the threshold of taking the same step, and the problems involved are different. The appropriation bill voted by the House all but wipes out funds available for iron ores at a time when the Nation needs every available effort from both governmental and industrial organizations in order to take the step with the greatest surety and efficiency. Iron work is being stopped at Laramie, Wyo. (rotary-kiln sponge iron), Raleigh, N. C. (Swedish-grade sponge iron by brick-kiln methods), and Tuscaloosa, Ala. (concentration of low-grade southern iron ores) and curtailed at Minneapolis, Minn. (sponge iron by gas reduction of Minnesota iron ores), and at Pittsburgh, Pa. (central-control laboratory of sponge iron). Curtailment of the Redding, Calif., laboratory (electric steel from sponge iron) to half-time operation is also involved.

High-grade bauxite is not plentiful within the United States, but very large supplies of low-grade bauxite are available in Arkansas. The present aluminum industry does not operate on low-grade bauxite as long as high grade can be imported cheaply. The closure of the Bureau of Mines, Bauxite, Ark., concentrating mill (50 tons daily capacity) abandons an important step toward security and self-sufficiency. Taken with the refusal to carry through the three RFC alumina pilot plants at Harleyville, S. C., Laramie, Wyo., and Salem, Oreg., it would appear that the Government is not interested as much in security as in immediate economy.

A pilot plant on electrolytic chromium and another on electrolytic cobalt, must struggle along on depleted funds with lessened efficiency at Boulder City, Nev. Electrolytic chromium as electrolytic manganese was unlike the corresponding forms of manganese. Electrolytic manganese found a definite mission in the mineral industry, despite its cost, and it is believed that the same fate awaits electrolytic chromium. Cobalt, in turn, is a metal of which we have a short supply and the best process that was developed for such domestic ores as the Nation has happened to be electrolytic. The process should be carried to the point where industrial use will be assured. The function of a pilot plant in carrying an innovation to a practically usable-end point is obvious.

Exploration during the war revealed a large area in Idaho and Wyoming where the phosphate beds contain enrichments of vanadium, a metal now largely imported The best vanadium seams are slightly below the top rich phosphate bed but could be mined with it. Most of the vanadium is extractable with the phosphate, as proven by small-scale and test-plant scale work in the experiment stations. Working the phosphate and vanadium together promises that this largest known concentration of vanadium known in the world could be made economically productive. Pilot-plant proof thereof is denied under the appropriation as voted by the House.

Zirconium is a metal of which the Nation has adequate supplies that are practically unused. Small-scale laboratory work and 4-pound test-plant work have developed what looks like a workable process for zirconium recovery. The metal is so resistant to many types of corrosion that it promises to compete with tantalum, a metal whose ores are largely imported. The metal also promises important surgical uses as well, and can well fill some of the uses now met by tantalum, platinum, and gold. A proposed pilot plant for 100 pounds per batch must be abandoned under the appropriation now proposed. Two commercial producers of nonductile zirconium have applied for licenses to operate under Interior Department patents as soon as the process has been proven, because the Bureau of Mines processes make zirconium of much higher purity, and it is ductile and workable.

In titanium-metal technology the Bureau of Mines operates two pilot plants, one on the extraction of titanium metal (in the form of a powder) from the ores, located at Boulder City, Nev., and the other on the physical metallurgy of the metal, compacting it into ingots, rolling, forging, swaging, wire drawing, etc., is operated at Salt Lake. Allotments of either rolled titanium or powder are made to governmental and industrial laboratories for testing as to possible uses. These allotments have proven so useful that there is a greater demand than can be supplied, particularly from the armed forces for improvement in weapons and instruments. Instead of reducing the scale of these two enterprises, they should be doubled or trebled at this time in order to accelerate the growth of an infant industry that promises to provide a domestic replacement for chromium and nickel involved in stainless-steel industry and to get improved metal for aircraft.

construction by lessening weight and increasing strength. The bearing of this development on security is of high importance.

Two wars have proven that peacetime is the proper time to operate pilot plants that deal with war preparedness. Funds are appropriated generously for pilot plants in wartime, but the delays in getting equipment and the difficulty in getting personnel make the policy almost futile. On the other hand, with meager funds the Bureau of Mines before the recent war developed through pilot-plant scale processes for recovery of flake graphite that permitted building of five commercial plants for recovering flake graphite. In the same way the extraction of lithium chemicals and concentration of lithium ores was worked out before the war and war-production plants based on all three of these processes were built in time to be really effective. A potash pilot plant funded in 1930 contributed to making the United States independent of Europe for its potash, whereas potash shortage was one of the worst in World War I.

MINING EXPERIMENT STATIONS

In the mining experiment stations originate the ideas that are later given first test-plant and then pilot-plant proof if they have been promising on the small laboratory scale. The attempt to cut back appropriations of experiment stations to prewar size, in terms of numbers of dollars, is obviously going to result in crippling them and greatly decreasing their efficiency. Several are now back to or below the prewar number of dollars, and more of them below prewar purchasing power. There are now 14 of them, 3 isolated pilot plants not associated with stations, and 8 field offices. Two experiment stations will be abandoned and two field offices. Two of the isolated pilot plants are also to be abandoned, together with nine others, under the appropriation allowable under the House bill.

The mining industry has experienced some permanent growth, the need of technologic work on mineral products grew, cost of operation grew, but the policy on appropriations shrank unduly. The heavy cuts made by the previous Congress wrung out most of the water, but the new cuts proposed will squeeze out blood from the Bureau of Mines appropriations. The Bureau of Mines cannot continue to be as important a contributor to development of the Nation's mineral resources as it should if this is allowed to happen.

Senator MALONE. Any comment you care to make on the material you are submitting we will be glad to have.

Mr. RALSTON. Yes. There are several things that I wish to call to your attention that are germane to the work of this committee. First of all, this statement shows the effect that the present appropriation bill, as advanced through the House, will have on our work. I have listed here the many things on which we have been working, their significances, what they are good for, and what their future will be, and I have included further information about the zirconium and titanium we have just mentioned.

I do want to call your attention to one thing, and that is vanadium. The United States imports a great deal of its vanadium. During the war exploration, there was revealed a very large area in Idaho and Wyoming where the phosphate beds are enriched in vanadium. The best vanadium strata in those phosphate beds are just below the top rich bed of phosphate rock but can be used to flux the phosphate rock in a smelting operation for phosphorous. The vanadium passes into a ferrophosphorus vanadium with all iron that was in the ore which separates from the slag of phosphate, so there is the opportunity to work them coincidentally. Now, that phosphate area is, I would say, while it is somewhat lean, it has the biggest known concentration of vanadium, I think, in the world.

Senator MALONE. You say the Idaho phosphate bed?

Mr. RALSTON. Yes.

Any new electric phosphorus furnaces put into operation up there should include vanadium recovery. The electric furnace will also

recover vanadium. We need to know how to get the vanadium into the ferrophosphorous vanadium alloy that will form—that you can't help having formed. We had a proposal for a pilot plant on that which had to be abandoned under the present bill. There is the opportunity to make the United States independent on vanadium. We have enough domestic material for a huge amount for years.

Senator MALONE. What are the principal commercial uses of vanadium?

Mr. RALSTON. It is principally used as an alloying element in steel. It is a very important one.

Senator MALONE. And there is no known substitute for vanadium?

Mr. RALSTON. Well, no satisfactory substitutes. In the alloy field we have the opportunity to substitute one thing for another a great deal and would get by if we had to.

Senator MALONE. What I really meant, Mr. Ralston, is that there is no known substitute of which we have an ample supply?

Mr. RALSTON. That is right. Substitutes that are satisfactory. We don't want to have to get along without it. It should substitute vanadium for more of the expensive and rarer alloying elements, and that is what Germany did. They proceeded to recover vanadium in their case, which was small amounts of vanadium in the iron ores.

Senator O'MAHONEY. What is the source of these more expensive alloys?

Mr. RALSTON. Frequently abroad.

Senator O'MAHONEY. So what you are telling the committee is—and I hope the press will get this one—that in the West, particularly in Idaho, we have the largest deposit of vanadium in the world, and that this deposit if properly developed can produce the substitutes for expensive and rare alloys used in the manufacture of steel which are available chiefly outside of the United States, but that the work of the Bureau of Mines to pioneer this development is being cut off by lack of appropriations.

Mr. RALSTON. That is right. We must defer at least.

Senator MALONE. Mr. Ralston, right at that point, this committee is intensely interested in that part of your testimony yesterday that showed, for example, that a commercial substitute for nickel, which is almost entirely imported, has been found. No commercial deposits having been found in the United States, 95 percent, I believe, approximately being imported from Canada. But a satisfactory substitute has been found in the form of metallic manganese, which is an electrolytic manganese method of production as worked out by the Bureau of Mines, and a pilot plant of Boulder Dam has been producing this electrolytic managanese, metal manganese, since that time, and also at Knoxville.

Mr. RALSTON. The Knoxville is commercial production.

Senator MALONE. Now, that is, then, a satisfactory substitute for something that we do not have at all and which is indispensable.

Mr. RALSTON. That is a substitute for some of the heavy uses of nickel, not a complete substitution for all of them, but a very satisfactory one for some of them.

Senator MALONE. Then I further make the point that at Boulder we have the Three Kids deposit of low-grade manganese, several million tons, and deposits in other places in the United States and that this electrolytic process has made available, commercially

available, the low-grade deposits of manganese that otherwise would have been unworkable.

Mr. RALSTON. That is right. We have closed the electrolytic manganese plant. It has advanced far enough so that we need not carry it any longer. It is nice to reach something of that kind and not have it go year after year on appropriations.

Senator O'MAHONEY. Perhaps it ought to be added here before you go on that this Canadian supply of nickel is under the control of the International Nickel Co., which is a well-known monopoly, so that all users in the United States have to pay what International Nickel wishes to charge.

Senator MALONE. Right at that point, Senator, as you know, I acted as special consultant to the Senate Military Affairs Committee during the war. I was in New Caledonia where we were getting large supplies of nickel and chromite, neither of which is produced in large quantities in this country—and this is subject to check—but my information was, and I so reported it, that the United States sold the entire supply to Australia, who in turn sold most of it to the International Nickel Co. Then we received our share of it on about the third transfer.

Senator O'MAHONEY. The curious thing was that France, which was controling New Caledonia, being overrun by the Germans, was nevertheless in such a position that International Nickel and the French interests were making the United States pay huge sums for the nickel necessary to beat Hitler.

Senator MALONE. I should say that we paid through the nose.

Some of these things are particularly interesting to the committee, as brought out by the able Senator from Wyoming: First, substitutes for material that is absolutely necessary both in peace and wartime, which is not produced here in sufficient quantities, and, second, the making of our low-grade deposits or deposits of mineral valuable where they otherwise would have had no value.

Then, coming to titanium. You testified yesterday that titanium was the fourth most plentiful metal on the earth's surface.

Mr. RALSTON. Most plentiful metal capable of structural use.

Senator MALONE. Capable of structural use.

You further testified, and you presented samples of the metal here this morning, that it was four times as strong and twice as heavy as magnesium metal.

Mr. RALSTON. Yes.

Senator MALONE. If used in airplane construction then, any structure made of this material could be made just as strong and half as heavy.

Mr. RALSTON. Correct.

Senator MALONE. That then is a great improvement over material that we now have. Those are the things in which we are interested.

Mr. RALSTON. Also that the titanium metal, even without alloying to increase its strength or any of its properties, is a typical corrosion-resisting metal and can substitute in part of the uses of stainless steel and therein substitute for nickel and chromium.

Senator MALONE. That is a very important point because our chromium deposits are limited and low grade. I think the largest known deposit is in Montana.

Mr. RALSTON. Yes.

Senator MALONE. It is not immediately available even with our own processing method.

Mr. RALSTON. This statement that I put in also includes a statement of our electrolytic chromium plant which can work on the low-grade ore of the United States.

Senator MALONE. I noticed that in your statement. I knew of this plant, but was not aware of the progress you made during the last year.

Mr. RALSTON. The electrolytic chromium is much different from the other form of chromium—I mean as electrolytic manganese differed from the purest manganese we can make in any other way.

Senator O'MAHONEY. Off the record.

(Discussion off the record.)

Senator MALONE. You can continue.

Mr. RALSTON. We were on chromium.

Senator MALONE. It is on page 2 of your statement.

Mr. RALSTON. Yes. Pilot plant on electrolytic chromium and another on cobalt, both at Boulder City, Nev., being asked to struggle along on decreased funds, and it will mean less in efficiency and it will take longer to arrive at definite conclusions on them.

I mentioned this comparison with electrolytic manganese. The electrolytic chromium we are not making in enough quantity to share with the research laboratories of everyone else who would like to work on it.

Senator MALONE. Have you reached a point in electrolytic chromium where you can see with reasonable sureness that it would be a commercial process eventually?

Mr. RALSTON. If I were starting over in a career in something in the mineral industry, I believe that that would be a very attractive place.

Senator MALONE. Electrolytic chromium?

Mr. RALSTON. That is right.

Senator MALONE. Electrolytic chromium is made of this low-grade chromium and is needed in rather large amounts?

Mr. RALSTON. That is right.

Senator MALONE. Proceed.

Mr. RALSTON. Most of that paper deals with those pilot plants, but I want to say a word about the mining experiment stations.

The ideas that have worked out in the pilot stations have originated in the mining experiment stations. The mining experiment stations are pin-pointed in the localities but not as to subject matter, so we can try any idea that we wish to on small scale in one of the experiment stations, and we do the pioneering and sifting and throwing out of bad ideas in picking the ones that are worth development in the experiment stations, and we do step from the test-tube scale to the wheelbarrow scale in little test plants in the experiment stations.

Now, that work should be maintained, but of our working stations, we are having to abandon two if this present appropriation goes through. Two of the large isolated pilot plants that are not associated with stations will have to be abandoned, and two field offices which are the outposts of the stations closer to grassroots for con-

sultation with people that want any kind of information, two of the eight field offices also having to be abandoned under this appropriation. That means in all cases that we are down near to a corporal's guard. The proposal on the experiment stations is to take them in appropriations back to prewar number of dollars, but the purchasing power of the present dollar—you can make your own estimate what it is—but you can see what it means. Some of those stations, and if you cut proportionately according to the House bill that we are facing, will be down below prewar in dollars, and many of them in purchasing power will be far below prewar conditions. It is a policy, I think, for the interest of the committee to see reversed.

Senator MALONE. Right at that point, Mr. Ralston—what do you find the purchasing power to be in comparison now as compared to say the beginning of the war? It would be important to know that in your comparison as to dollars and purchasing power.

Mr. RALSTON. Well, we have had several raises in pay of Government employees.

Mr. T. H. Miller, can you help me as to what they were and what proportions——

Senator MALONE (interposing). Approximate percent—20 percent——

Mr. T. H. MILLER (interposing). I think one was 10 percent and one was 14. It varied over the different grade levels.

Mr. RALSTON. Yes. The lower levels were also given a third hike.

Senator MALONE. Then materials, of course, are more expensive; are they not?

Mr. RALSTON. Oh, yes. Nearly all machinery costs twice what it did.

Senator MALONE. The labor, then, is 25 percent higher and the machinery about twice as high; it would be a third additional expense.

Mr. RALSTON. The labor at a minimum is 24 percent higher and the lower levels of which we have many people are still another 10 percent or so.

Mr. MILLER. I believe the first salary adjustment that took place was in what we call the subprofessional grades where they had a substantial reclassification for the 1946 Salary Act. In other words, it costs us about 40 percent more for the general conduct of Bureau business before the war, 1940 or 1939 level.

Senator MALONE. It would require, to continue the same operation at the same level, a 40-percent-greater appropriation.

Mr. MILLER. I would like to have that figure checked for the record, but I believe it was about 40 percent.

Senator MALONE. Thank you. It is close enough.

Mr. RALSTON. With your permission, we will enter any correction on the record when we read our copy of it.

Senator MALONE. Yes, sir.

Mr. RALSTON. Now, in that connection in this statement, the paragraph I would like to read to you is as follows:

> The mining industry has experienced some permanent growth, the need of technologic work on mineral products grew, cost of operation grew, but the policy on appropriations shrank unduly. The heavy cuts made by the previous Congress wrung out most of the water, but the new cuts proposed will squeeze out blood from the Bureau of Mines appropriations. The Bureau of Mines cannot continue to be as important a contributor to the development of the Nation's mineral resources as it should if this is allowed to happen.

Senator MALONE. Do you have any further statement to make, Mr. Ralston?

Mr. RALSTON. One thing that I did not put in here, which is an oversight, is the fact that we do have some nickel. The war exploration revealed attractive amounts of nickel in several places in the State of Washington and even bigger amounts in Oregon. We have a small pilot operation going on there and must cut about in two this coming year. There is some domestic nickel that might be put to work, or at least the technology developed that will let us use it in time of war. I think that the experience of two wars is enough to prove to me, and to nearly everyone that I talk with, that the time to operate pilot plants for things that may be needed in war is not in wartime. It should be in peacetime. We did some work on graphite a few years ago before this last World War. The five plants erected by the Government for production of flake graphite were based on that work. We were ready when the war came; the plants were designed and operated in time. If you will wait until the war, when they get very generous with appropriations, for pilot plants, most of them don't get the job done in time to be effective. One of the worst shortages of the First World War was potash. We depended upon Germany and France, and we had a time in this country, and we came out with the avowed purpose of everybody to make this country independent. It wasn't until 1930 that we got an appropriation for a 5-year job of pilot plant and exploration in the field. The exploration in the field brought up the exploration started first—that was a little before 1930—brought out the Carlsbad area, and as a result of the united efforts of everybody interested this country became totally independent of everybody else on potash. That was one pilot plant that the appropriations came 12 years after the lesson was learned in the other war, but it did come, and it was effective.

Senator MALONE. Mr. Ralston, I would like to ask you another general question. I know of your wide experience in this field, and your principal work for many years has been in developing either substitutes for hard-to-get minerals or processes that would make our own deposits workable. Of the necessary strategic minerals in this country, called strategic because we have had trouble in producing sufficient for our own needs, especially in wartime, how many of these materials, in your opinion, might be made available in this country in sufficient quantities if work of the kind that you are conducting could be continued? That is to say, in developing substitutes, as in the case of electrolytic manganese for nickel or in developing processes that would make our own low-grade deposits available, such as electrolytic chromium methods.

You might put it the other way around if it would be more convenient to you. What, in your opinion, would be the remaining metals in which after a few years we still could not be made self-sufficient?

Answer it either way you care to.

Mr. RALSTON. Well, of the 96 known elements in the earth crust, between 40 and 50 are metals, and industry uses maybe half of those at the present time. Titanium has not been used very much, and it still isn't what you would call much of an industrial metal. You can see the fact that it has been ignored and forgotten, the fact that we find it has physical qualities that might justify us in saying that the

stone the builders rejected looks like it can become the headstone of the corner.

Senator Malone. Now, right at that point I was intensely interested in your testimony. Titanium, as developed, is not only a metal by itself that would be good for other uses, but, according to your testimony, being so much stronger and only a little heavier than magnesium, could take the place of magnesium that is used in place of building materials where often aluminum is used. Also, then, your pilot plants that were developed in the alumina plants to take the place of bauxite, would provide ample supplies.

Mr. Ralston. Not only in these twenty-odd neglected metals but in the minerals that are not used to make metals. There are perhaps 500 of the minerals known that are mined and dealt in commercially, and when they get down to the list of strategic and critical, you will have most of these 20 metals in some way connected with them. I think we could easily extend the total list of strategic materials to 75 by taking into account all of the minerals.

Cryolite, produced in Greenland only, can be made synthetically. Germany had to do it. We had to do it. It is no problem. We can expand on that.

Senator Malone. This is to take the place of cryolite.

Mr. Ralston. Yes. But cryolite is just one of those that is according to the definition of strategic mineral, something that is almost entirely produced abroad.

Senator Malone. What are the specific uses of cryolite?

Mr. Ralston. That, of course, is the backbone of the aluminum electrolytic cell. The electrolytic medium in which you dissolve aluminum oxide, pass the electric current, and make metal. It is absolutely essential to the aluminum industry. It is just one of those examples of minerals that should be rated strategic.

Senator Malone. Then, you only have one alternative—you either have to produce this substitute, of which you have spoken, or you would have to have extensive stock piles of this material in order to be safe?

Mr. Ralston. Yes, sir.

The operators of the aluminum plants still prefer the natural cryolite over the synthetic, especially in starting a plant.

Senator Malone. If you would prefer, Mr. Ralston, you can take your time and prepare a statement answering my general question. Speaking extemporaneously you might overlook some of the materials. I think the committee would be interested in a carefully prepared statement of that kind.

Mr. Ralston. Yes, sir. We will. I can point to one—asbestos. If we could synthesize an asbestos fiber, we would be supplying something of which we have almost none.

Senator Malone. Is that possible in your opinion? And what experiments have been conducted in that regard?

Mr. Ralston. We have done nothing. I have seen no experiments that convince me that anyone has a good substitute. The nearest thing to it is glass fiber, but it still falls far below what is necessary.

Senator Malone. In your opinion is there a possibility in that field?

Mr. Ralston. Well, nature did it. Most of the things that nature can do we can duplicate some time, unless it takes a geological epoch

and time to do the same job. Diamonds have been synthesized. People still think they can synthesize diamonds. We recently took a diamond drill bit and substituted a hard carbide especially prepared in exactly the same quantity and size of particles as in a diamond bit, and it drilled one-third as far as the diamond drill bit did. Diamond drilling of blast holes in mining is coming in, and is demanding more of the industrial diamonds than there is a supply. That use is going to have to pause until we can get a substitute. I believe that if we used our same hard carbide in bigger quantity in these diamond drill bits than the same quantity, there is no use why we shouldn't use three times as much, and I think we will equal the performance.

Senator MALONE. And the advantage would be that we would make it in this country from materials in this country.

Mr. RALSTON. Just exactly. That isn't very expensive work. You only work on a gram or two at a time, and anybody can do it in the milkshed.

Senator MALONE. Do you have any further statement?

Mr. RALSTON. No. I think I have covered most of the points.

Is there anything you would like to have me bring up, Mr. Miller?

Mr. MILLER. Not at this time.

Senator MALONE. Thank you, Mr. Ralston. It has been very interesting, and the committee will feel free to call on you in the future if anything comes up in your field.

Now, Mr. Pehrson. We will hear from Elmer W. Pehrson, who is chief of the economics and statistics branch of the Bureau of Mines. Mr. Pehrson is well known and has had a long experience in this field. He is recognized as an outstanding statistician and has, I believe, been responsible for most of the work in that department in the Bureau of Mines.

STATEMENT OF ELMER W. PEHRSON, CHIEF, ECONOMICS AND STATISTICS BRANCH, BUREAU OF MINES

Mr. PEHRSON. I would like to have the record show that I am a graduate mining engineer. I have been in the Bureau of Mines since 1928.

Mr. Chairman, I have no prepared statement to offer. It was my understanding that I was up here primarily to answer questions on the reserve report and any other questions of a general nature in which I might have competence.

I might, however, give briefly the background of the preparation of the report. For one thing, I would like to call attention to the fact that, even though the report is restricted to 39 minerals, it includes all the important industrial minerals. It does not include a great variety of nonmetallic minerals in which the United States generally has an abundant supply. So that we feel that the elimination of those commodities from this report has not in any way minimized the value of the report. This covers all the other important industrial minerals and all the minerals on which we can anticipate problems at some time in the future.

I make that statement in view of the fact that yesterday you seemed to have some question about the coverage being restricted.

Senator MALONE. I presume, Mr. Pehrson, too, that the committee can get further information from your Department beyond 1945. I

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notice that 1945 is the last year in the charts and maps. I presume you could prepare a 1946 information for us, could you not?

Mr. PEHRSON. Not all of the 1946 official data have yet been completed.

Senator MALONE. When do you think that might be complete enough for you to furnish additional information later?

Mr. PEHRSON. I would say midfall before all of our work is completed. It will be particularly slow this year in view of the fact that we are dropping a very large proportion of our staff, so the whole process has been slowed up.

Senator MALONE. I ask you this general question then, Mr. Pehrson. Do you agree in substance with the testimony of Mr. Ralston that you just heard in the matter of metallurgical experiments and advancements in the production of strategic minerals?

Mr. PEHRSON. With the general philosophy of his statement I am in agreement. As far as the technical end is concerned, I don't feel I have sufficient background to pass competent judgment.

Senator MALONE. That is sufficient. I know you are entirely familiar with Mr. Ralston's work.

Mr. PEHRSON. There is one point I would make, however, in connection with what he has stated, and that is that the development of a process for utilization of low-grade materials does not necessarily solve the problem of self-sufficiency. Frequently there has to be an economic incentive in addition to the technical process. For example, the only commercial plant now operating on electrolytic manganese has turned to foreign ores, so while we have a new metal for industry, and we do have a method by which the domestic resources can be used in an emergency, we have not yet solved the problem of self-sufficiency.

Senator MALONE. I guess it would be the interpretation of the word "self-sufficiency," self-sufficiency in national defense. We would be self-sufficient if we did not take into account the economics of production. We could be made self-sufficient in the low-grade manganese ores found here .

Mr. PEHRSON. Yes.

Senator MALONE. And it is the question of the additional expense in handling the low-grade ores found in this country and the higher grade foreign deposits that make the manufactures of electrolytic manganese turn to the foreign deposits at this time.

Mr. PEHRSON. That is correct.

Senator MALONE. But they could use the low-grade deposits in case of war.

Mr. PEHRSON. Yes; if costs were disregarded.

Senator MALONE. Now, those costs have been improved, have they not, through your experiments?

Mr. PEHRSON. Oh, yes; I think as a result of the Bureau's work, private enterprise has been encouraged to step out in this pioneer industry, and the experience of industries in general is that as they gain experience costs will come down.

Senator MALONE. The important point would be, however, that we do have the material to produce the necessary manganese in case of war or other emergencies.

Mr. PEHRSON. That is correct.

Senator MALONE. Now, right at that point regarding the economic aspects—do the different living standards in the other countries have

something to do with the cost of mining and producing the manganese as well as other metals?

Mr. PEHRSON. I think there are two major factors. One is the cost of labor and the other is the richness of the resource. There are differences of opinion on how serious the difference in wage scale really is. There are some people who believe that the greater efficiency of American engineering practice overcomes to a substantial extent the difference in wage rates.

Senator MALONE. Is it a fact that our machinery and engineering and ingenuity are available now to these foreign deposits in the case of copper and some others?

Mr. PEHRSON. Very definitely so. That is a trend of the last 20 years which I think in the long run will eventually make the wage differential an extremely important item in the international competitive markets.

Senator MALONE. It will be extremely important.

Mr. PEHRSON. Yes.

Senator MALONE. You have made, then, the exact point that I meant to bring out—that eventually, and the time is probably very close, our own machinery and our own engineering and our own ingenuity, as you might say, will all be available to all foreign countries. Then, wage differentials and labor efficiency will determine the difference in cost if deposits are of somewhere near size and grade.

Mr. PEHRSON. Size and grade.

Senator MALONE. Now, that brings up the next point that this committee is very much interested in, and that is how to keep this country in production, producing the material that it can produce in competition with the lower living standard of European countries, even Asiatic countries, until such countries can reach our standard of living, as I remarked in the opening of our hearings. There are 55 nations in the United Nations Organization, and there are 55 different living standards. Then, there is a real problem of maintaining our standard of living and maintaining our own production, even in the minerals and the materials where we have ample supplies; is there not?

Mr. PEHRSON. I would say so; yes, sir.

Senator MALONE. I hope and am sure that the beginning testimony of the Secretary yesterday, supplemented by technicians, will show us the status of our own country here and its ability to produce the needed materials, and show where we are headed in the metallurgical experiments so ably outlined by Mr. Ralston. Then we will come to the next point as to how to maintain production in our country. This is another question entirely, but it is an important question, because cost of production will eventually—according to your own conclusion, to which I agree—depend upon wage differentials and standards of living in the different countries. If we want to continue production of the same materials, differential costs will have to be taken care of, either by subsidy or premium payments or tariffs—do you agree with that?

Mr. PEHRSON. I agree with the statement on this premise, that if it is determined to be the policy of the Nation to maintain production through subsidy or other devices for assisting domestic producers, that it will have to be accomplished through the method that you suggested.

Senator MALONE. If we want to stay in business and maintain our standard of living, some method must be found to do that. You agree with that?

Mr. PEHRSON. That is correct.

Senator MALONE. This committee is interested in determining and presenting the evidence to the Senate on, first, what it is possible to do in this country, and, secondly, how it may be done logically. We expect this will not be done in a day. It will take a little time. But starting with the Department of the Interior, we hope later to hear from other departments that have something to offer, as well as the industrialists, those that are producing this material the hard way out there in the mines and various places, of which you are entirely familiar, so that the summation of the evidence will produce some approximate answer. That is the objective of the committee.

Do you have any further comments on the report or general comments you would like to make, Mr. Pehrson?

Mr. PEHRSON. I would just like to state that during the war we experienced many difficulties in maintaining mineral supply, and as a result of that certain people adopted a very alarmist attitude as to the status of our domestic mineral resources. The statement that we were rapidly becoming a have-not nation was widely publicized, and those of us in Washington who had been intimately concerned with minerals for many years felt that a distorted picture was being given. It was suggested that the Bureau of Mines and the Geological Survey undertake an appraisal of our mineral position. Because the Survey had studied the mineral resources of the United States since 1880, and the Bureau of Mines since 1910, and also because of the fact that during the war we collected in the war agencies and in the two bureaus considerable information that ordinarily would not be available to Government agencies, it was felt that we were in a better position at this particular time to appraise our mineral resources in realistic manner.

We recognize that the amount of knowledge that would be required to appraise our ultimate mineral wealth is infinite, and we have only a very small fraction of that information available at the present time. Nevertheless, it was felt that an appraisal of our resource position by experts in the Government who are in a position to view the job objectively would be a very helpful project. This viewpoint was adopted by the directors of the two bureaus and approved by the Secretary of the Interior. So, early in 1944, we set up a joint committee of the Geological Survey and the Bureau of Mines to supervise the job. I was privileged to serve as chairman of that committee. One of the things that we learned from the study is that the two bureaus are carrying such a load of regular work that to superimpose a major job of this kind over the regular work is an extremely difficult thing; so a project we expected to finish in 6 months was drawn out over a period of 3 years, and even at that I can testify, and I think Mr. Bannerman will agree, that most of the work was done on an overtime basis. But, nevertheless, we completed the report.

The reserve estimates are based on data available as of 1944. Since then there has been some reconsideration of the material in the report, but it was generally believed that no useful purpose would be served by revising the estimates in the light of additional information which had come to our attention in the last 2 or 3 years.

I would like to emphasize that in interpreting this report, too much emphasis should not be given to a specific figure. It is not too important if the reserve of this or that commodity is equivalent to 2 or 10 years of supplies. We are dealing here with rather general orders of magnitude. I think the significant points to be taken from the report are the imminence of declining self-sufficiency in some minerals, the fact that we are abundantly supplied in many minerals, and that those fortunately include minerals that are most fundamental to the maintenance of an industrial society. And also I think we should frankly recognize that there are a good many minerals that the United States does not possess in any quantity at all either in the form of commercial reserves or submarginal reserves, and that we must reconcile ourselves to continued dependence on foreign sources.

Senator MALONE. Right at that point, Mr. Pehrson—those would be the minerals, as brought out by Mr. Ralston, that should be subject to stock piles when it is determined that certain minerals are necessary in an emergency and are not available and as yet no metallurgical experiments or discoveries have brought out substitutes.

Mr. PEHRSON. They certainly should; and, of course, I think others should be, too. I think we should have a very comfortable stock pile of every mineral in this country.

I think our national policy should be oriented to the importation of the deficient minerals with a minimum of restraint.

Now, there are one or two points that I would like to emphasize at this hearing that perhaps are not tersely expressed in the report. The United States is abundantly supplied with the minerals that are basic to our steel industry, iron ore and coal, and we are abundantly supplied with the fertilizer minerals. We also have other minerals in abundance. We have had up to the present time ample supplies of petroleum. There is some question as to the future outlook of petroleum. But there is no other industrial power in the world, with the exception of Russia, that can attain the same degree of self-sufficiency in these minerals of such vital importance.

Senator MALONE. Right at that point, Mr. Pehrson—I think your own reports show, and I am sure you agree with me, that as far as oil for national defense is concerned, we do have a reserve in oil shale almost equal to the estimated reserves under ground.

Mr. PEHRSON. We have very large submarginal sources of petroleum.

Senator MALONE. To bring out that particular point again, there is no danger of running out of oil for wartime if the cost is not considered?

Mr. PEHRSON. That is correct.

As I said, no other industrial power, except Russia, can marshal such self-sufficiency in the basic minerals. Also, I think we should take note of the fact that in the United States we have been extracting our mineral resources much more rapidly and in much greater quantity than any other nation of the world. I believe there is general agreement that in the Eurasian Continent the potential resources are extremely large and depletion has not advanced very far, whereas in our country it certainly has progressed considerably, although opinions differ as to the extent our resources have been exhausted. I think we should also bear in mind that in the future any industrial powers on the

Eurasian Continent will probably dominate Africa; so that would give the Eastern Hemisphere access to mineral resources that, I believe, will be considerably more potent than the resources in the Western Hemisphere. Therefore, in dealing with our mineral problems, I think we should take a very long-range view of this situation and also keep a weather eye on the international situation.

Senator MALONE. By the "Western Hemisphere" you would mean North and South America?

Mr. PEHRSON. North and South America.

Senator MALONE. Well, in your investigation, if you have made one, are there not many minerals that are of lower grade or scarcer in this country which are available in South America—like, for example, manganese?

Mr. PEHRSON. The resources of manganese, I should say, of Brazil are considerably larger than those of the United States, and they are higher grade.

Senator MALONE. So far as we know, there are plenty of supplies?

Mr. RALSTON. Plenty supplies of off-grade materials in the Western Hemisphere.

Senator MALONE. There are plentiful supplies of rather high grade in Brazil?

Mr. PEHRSON. If you mean by "high grade" the standard grades of commerce today, I don't think that would be true.

Senator MALONE. Go ahead, Mr. Pehrson.

Mr. PEHRSON. I don't know how much you want me to go into this report, Senator.

Senator MALONE. In general, Mr. Pehrson, I would like any information that you are able to give us on your own definition of your survey. I believe it should be made in line with your statement that your estimates in this report were not to be taken seriously in the matter of 1, 2, or 3 years' supplies. You have made there what we might call an inventory—correct me if I am wrong—in which you have listed the known resources and given some attention to the grades and the possibility of utilizing the oil. I have not read your report carefully as yet, but as regards possible development, that is another field entirely. There we might go into the encouragement of venture capital in the fields of development, and the fact that mining is a speculative enterprise and not subject logically to the regulations that a building could be subject to. At least you show you have the building when you put your money in it, but in mining it is absorbed in development work; you just hope you are going to find something. At least, the money is gone anyway, so it is a speculative business; is it not?

Mr. PEHRSON. That is correct.

Senator MALONE. The only time it becomes a real business is after you have expended your money in drilling the property thoroughly and blocked out ore, all of which is very expensive; is that true?

Mr. PEHRSON. That is correct.

Senator MALONE. So the first money expended, you might say, is gambling money, speculative money. When it is too closely regulated—that is something we will take up a little later—we could prevent such development and such expenditure; is that true?

Mr. PEHRSON. I have made no study of the regulation of risk capital. It is true that venture capital in mining is certainly more highly specu-

lative than in any other branch of industry that I know of. Under normal conditions, it seems to me, that capital is available for venture exploration if the prospects of successful results are good enough.

Senator MALONE. But how do you arrive at the point where these prospects for successful developments are good enough? Aren't the prospectors and the wildcatters the ones that keep these prospects good enough?

Mr. PEHRSON. I personally feel that we have passed that stage, Senator. I think the day of finding important ore deposits in this country by traditional methods is over. If we are going to be successful in finding the hidden deposits, which I think most everybody will agree probably exist under cover in this country, we shall have to indulge in some new method of prospecting.

Senator MALONE. Well, is it not a fact that these new methods that you speak of are simply additional factors in the discovery of such metal like the geophysical work and others, the mapping, such as was outlined yesterday so ably by Dr. Wrather, so that you never do get away from the necessity of walking out over the ground, in prospecting? It is like the Infantry in war. We have all kinds of methods of warfare, but nobody has ever been able to do away with the foot soldier yet. You still have to be a prospector and go out and spend time and money in following up or in trampling over the ground.

I suppose you know that one of the greatest gold discoveries in the West in probably 30 years was just an accident, north of Winnemucca, Nev., 4 or 5 years ago. As a matter of fact, you can follow this through, as far as I know, in almost all the great discoveries in the West. If these prospectors were not because of rules and regulations, or lack of rules and regulations, encouraged in going out and spending their time and money, perhaps the accidents wouldn't happen. But when one comes down to the actual discovery, it is generally something that you stumble on. Like, for instance, your Bureau up in northern Idaho prospecting for antimony and finding the largest tungsten deposit in the country, the highest grade. That is what I mean by venture capital. We will get into that later. I don't intend to take it up this morning.

We think the Securities and Exchange Commission in treating the mining industry as a business is making a great mistake in retarding the discovery of ore, and we intend to take that up in some detail.

We also think that any rules and regulations by your Department that regulates the mining industry beyond assisting in making these lower-grade ores available for industry, and marketable also, retards the mining industry.

I might say in connection with your statement I am very glad you have clarified this morning that what you have are simply inventories, that is, blocked-out ore in sight or readily available, and that you do not mean that 10 years from now 2 or 3 years' supplies will be available. You have been widely misquoted in the press, and I regret that. Perhaps even more than you know.

Mr. PEHRSON. The point I am trying to make here is that our estimates of commercial reserves are the best that we can make with our present knowledge of mineral resources. The estimated reserves when measured in terms of annual needs do indicate that our reserve

position in many important minerals is decidedly unsatisfactory. I make no apology for the report in this respect. I think it is sound and useful and indicative of where we stand at the present time. We show our commercial reserves of mercury as equivalent to 2 years of supply in the terms of the average annual consumption in the past decade.

Senator MALONE. What were the reserves of mercury, say, 15 years ago?

Mr. PEHRSON. Known reserves of mercury?

Senator MALONE. Were there reserves of mercury 10 years ago? What were the reserves then?

Mr. PEHRSON. I don't believe we have any information on that.

Senator MALONE. I live in the mercury country, and there were at least 2 years' reserve then.

Mr. PEHRSON. The significant thing in mercury is that we reached our peak of production in 1877. There has been a very sharp decline in our ability to produce in the intervening years, and while it is an industry where reserves are developed as you mine your product, we certainly must be far advanced in depletion of our mercury resources. This is important. Whether only 2 or 10 years' supply remains isn't particularly significant.

Senator MALONE. Right there at that point I would like to make a further point, Mr. Pehrson. That is, to elaborate somewhat on the point that was made by Dr. Wrather yesterday, and I hope to get some further information on it from some of your people that the cost or the market price determine largely the grade of ore you can mine and the activity in the mines and therefore the production; isn't that true?

Mr. PEHRSON. That is correct.

Senator MALONE. In other words, when the price went to two hundred and two hundred and twenty-five dollars a flask during the war, mercury began to come in that had perhaps no relation whatever to the estimated reserves you now have. It was low grade. When it goes down to $70 a flask, all of the marginal properties, so-called marginal properties are out of operation and there is very little incentive to prospectors to prospect mercury. Now, it is that incentive of price that we give more attention to as we go along. Do you agree with that?

Mr. PEHRSON. Within the limits of the resource price is a powerful incentive. Of course——

Senator MALONE. How do you determine the limits of resources underground?

Mr. PEHRSON. That involves a matter of judgment. Certainly I think nobody would dispute the statement that at any price within reason we could not produce tin in this country, and we have the experience of mercury that we cannot maintain self-sufficiency in this country except at a price of $200 a flask, and that compares with the world price at the present time of $65.

Senator MALONE. I want to get this particularly straight right at this point. Either your testimony this morning has toned down a good deal or else you have been widely misquoted in this country. With mercury at $200 a flask this country did almost become self-sufficient during the war.

Mr. PEHRSON. That is correct.

Senator MALONE. At $65 a flask we perhaps would produce very little mercury.

Mr. PEHRSON. That is correct.

Senator MALONE. Now, then, we have the three points that I wish to make, which will determine whether or not we will stay in the mercury business in this country. There are first, national security; second, employment; and, third, the development of taxable property. Now, the Congress of the United States has to fix this policy, as I see it. What I hope to do in this committee as chairman and what this committee hopes to do, is to conduct a thorough examination, starting first with the available supplies as estimated by your Department. I consider this the outstanding department in this business and very, very reliable, and I think you have some of the best men in the entire world in that Department. It would be very unfortunate if any of these men would have to be dropped by virtue of lower appropriations, and I do not believe there is any intention to interfere with the work of those men, but I will say at this point that I believe, as a good friend of the Department, that you have gone clear beyond your prerogative in saying what the country should do. That policy is going to be determined in Congress and by executives of the Nation.

Mr. PEHRSON. May I comment on that?

Senator MALONE. I want to complete the statement.

There are two thing that this committee wants to consider: First, we want to determine from the best information available, which I believe to be through your Department, what are the possibilities; second, we have to determine if through lower-grade deposits and higher wages, $8 or $9 or $10 a day to miners in our country, from 30 cents a day up in the foreign countries with their lower standards of living, whether we want to tend to lower our standard of living through imports, through reciprocal trade agreements, empire preference rates, and manipulation of foreign currencies to come under tariffs. Those are the things that this committee will follow through. They are starting with you, to determine what the present possibilities are and what you are doing and what we can encourage you to do.

In other words, what can we do to keep up the standard of living in this country by maximizing our production here.

Now you may proceed.

Mr. PEHRSON. First of all, you made a statement which implied that the Bureau of Mines was injecting itself into policy matters. I don't think that the facts will bear that out. We approach our job strictly on an objective basis. There are occasions when some of us are asked to analyze certain problems, and at times we do that. I, myself, have been asked on various occasions—I haven't volunteered anything—and as far as this report is concerned I can assure you it is absolutely devoid of any policy implications one way or the other.

Senator MALONE. I sincerely hope it is.

Mr. PEHRSON. The fact is that resources, so far as we know them now, are seriously depleted in some directions and it calls for dynamic action if the country wants to maintain its self-sufficiency. So far as individuals are concerned, we are bound to have differences of opinion, and I will be glad to express mine on any point you are to ask. I will do it without bias and without fear.

Senator MALONE. I will just recall a couple of points in order to refresh your memory. We have had in this country a policy of encouraging mining through the location of mining claims. This is carried out on Government domain where a prospector can go out and look for minerals. If he finds anything, or has a prospect, he can locate a mining claim. That claim belongs to him as long as he does the assessment work, which is fixed at $100 per year. Generally they do much more if they have any prospects. If a miner has done $500 worth of work and figures it is worth $5 an acre to him and the expense of the patent survey and the patent work, he can patent that claim so that it belongs to him. It is practically the only business in America where a man without capital at all can go in business if he can find an outcrop. The Federal Bureau of Mines has continually, over a period of 10 years, advocated that they revert to the leasing system so they can fix their own system of leasing and virtually control the prospector. I call that fixing mining policy.

Mr. PEHRSON. I am sorry, sir, but I don't think the Bureau of Mines has ever commented on that point.

Senator MALONE. It is in the Secretary's report to the President at this time.

Mr. PEHRSON. I think you have reference to the Office of Land Management, the old Land Office.

Senator MALONE. I have reference to Secretary Ickes and Secretary Krug.

Mr. PEHRSON. I can only speak for the Bureau of Mines.

Mr. MILLER. So far as I know, the only case where the Bureau of Mines has had any voice in setting a lease or royalty has been where the Bureau has been asked to do exploration work on fee-held coal land where the owners themselves subscribed to the repayment of a royalty. We have a few contracts of that type that have been written on coal contracts of that kind.

Senator MALONE. I am not particularizing, and I had no thought of going into it at this time; that is the reason I didn't question Secretary Krug about it yesterday. I consider any statement made by the Secretary of the Interior, who is in charge of the Bureau of Mines, as a policy coming from the Bureau of Mines and coming from the Secretary of the Interior and not from the technicians. That is one thing I have in mind that is going to clear out the prerogatives to do that.

Another thing that I think the Bureau should be very careful about is the issuing of statements, perhaps based on the best statistical information you can get, that this country is on the verge of running out of some certain material or some other material unless they might be asked by some congressional committee or the Executive of our Government which is interested in carrying on these experiments; it is a very dangerous thing, these partial statements that are misinterpreted.

As a matter of fact, all over the United States they believe that we are a have-not nation in minerals. It is something that I do not intend to go into at this time, but we do intend to go into it to a great extent in this committee.

I believe that your field is just exactly as you have covered it in this report. The testimony of Mr. Ralston this morning is exactly in line with enlarging these reserves to find out what could be the balance between these three things I have mentioned to you—national security,

employment, taxable property to keep this country on the living standard it now has. I do not believe it is the prerogative of any Government official to fix those. It is the power of the Executive and the Congress of this Government. I think you are one of the best statisticians I have ever seen.

Mr. Pehrson. I certainly want to emphasize that the Bureau of Mines is thoroughly in accord with your concept of policy making with respect to a Government bureau.

Senator Malone. Thank you, Mr. Pehrson.

Do you have any further testimony to offer?

Mr. Pehrson. No.

Senator Malone. Thank you very much.

Mr. Harold M. Bannerman, Chief, Division of Economic Geology of the United States Geological Survey, will be our next witness. Mr. Bannerman, if you have any written statement you may present it to the record and make any comments you care to in your own way.

STATEMENT OF HAROLD M. BANNERMAN, CHIEF, DIVISION OF ECONOMIC GEOLOGY, UNITED STATES GEOLOGICAL SURVEY

Mr. Bannerman. I have a short statement here, Senator, which I would like to introduce because it points to things that are not in this volume [indicating report] to some extent.

I concur entirely with what Mr. Pehrson has said concerning the nature of the mineral resource volume, that it is factual as far as our present data will permit; it sets forth the information as a cold-blooded factual statement with a minimum of technologic interpretation, and that is all.

We began the task of evaluating present knowledge of the mineral reserves of the United States in the early winter of 1943–44. By making use of the staff of specialists then on duty in Washington on work related to the war program, we were able to carry the project through with such dispatch that by June 1944 authors' copies of the chapters on each of the various mineral commodities—39 in all—were ready for critical review. Then pressure of other events forced us to reassign personnel to more urgent tasks outside of the District with the result that to a few of us was left the job of trying to evaluate, coordinate, and standardize the method of treatment, and to prepare the interpretative prefatory chapters necessary to set the data in their proper perspective.

Early in the war the United States Bureau of Mines and the United States Geological Survey agreed upon a terminology designed to measure the amount and degree of dependability of information available on the reserves of a given deposit. The terms measured, indicated, and inferred were adopted for this purpose and defined as follows:

"*Measured ore*" is ore for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are so closely spaced and the geologic character is so well defined that the size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within limits which are stated, and no such limit is judged to differ from the computed tonnage or grade by more than 20 percent.

"*Indicated ore*" is ore for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to outline the ore completely or to establish its grade throughout.

"*Inferred ore*" is ore for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition for which there is geologic evidence; this evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred ore should include a statement of the special limits within which the inferred ore may lie.

The meanings circumscribed by these definitions set the pattern which was followed by our geologists and engineers in their attempt to evaluate the available data on reserves in specific properties and collectively for entire districts. With our long-time records and rather widespread coverage, augmented by information obtained from the voluminous records of several war agencies, we were able to add up some sort of estimate of most of the known deposits that are producing or that are likely, within reasonable forecast, to produce. In my opinion, the three terms used would cover all that is known and that can be extrapolated with any degree of safety from information at hand regarding known deposits of the commodities included. However, they do not cover a very important item, that is, occurrence of geologic formations which have proven favorable in other areas and which might be found to be ore-bearing if adequately investigated.

In terms of over-all national reserves, this blind area subtends a very large angle in the thinking of geologists and engineers who are exploration-minded; yet the only evidence for the existence of ore in areas of this kind is the history of geologically similar regions and the imaginative thinking of men who like to prospect. We cannot include an estimate for such areas in so many words, but in interpreting our results in terms of the future of the industry it would be unwise to ignore the possibility that they may contain important deposits, and that, in the not too distant future, ways and means may be devised for detecting deposits in such areas. Undiscovered ore, for example, may be covered with younger nonproductive formations, such as later lavas or sediments, or lie beneath the wide waste-filled valleys that occupy a large proportion of the surface of any mineralized area. Indeed, it is possible that per unit of area the mineral deposits in the covered portion may be as abundant as where the productive formations are exposed, and if not too deeply buried, eventually they may be discoverable.

As regards the sources of data used in preparing the USGS-USBM mineral resource volume, a very large part of these data were accumulated over the years by the geologists and engineers of these organizations in the course of their normal activities. In very many instances, however, the data were augmented enormously by purposeful appraisals of hundreds of specific deposits examined during the war by the geologists and engineers of these agencies or of other governmental agencies such as the Metals Reserve Company and War Pro-

duction Board. A great many data were, of course, obtained directly from the mining companies for use in war production planning, and in a few instances, additional information was obtained from mining companies for the express purpose of including them in this estimate.

During the war the mining industry was exceedingly generous in making available to the officers of the Government such information as they had with regard to production records and reserves. In many instances, however, these data were given in confidence, and this fact posed many problems when we attempted to convert specific data from a form in which they could be used for planning war production to a form in which they could be used to express the over-all reserve of a district or region and, at the same time, keep faith with those who gave us the information.

Data on measured and indicated reserves were derived, therefore, from mixed sources. They are, by all odds, the more dependable estimates in the report, but their handling involved some very real headaches when it came to compiling them. The figures given with reference to the inferred reserve are largely our own. Undoubtedly they vary greatly in point of accuracy from place to place and commodity to commodity, depending upon the completeness of the record, the detail known concerning the geologic setting, and, to a very large degree, upon the temperament and experience of the man or men who made the specific estimate. In my opinion, the figures on inferred reserves are likely to err on the conservative side, because it is difficult for anyone to anticipate all of the fluctuating interrelated economic and technologic factors that are involved when one attempts to establish a commercial cut-off, and because of the innate tendency of geologists and engineers to be conservative when asked to place estimates on paper.

Estimates of reserves on a national basis, no matter how carefully prepared, cannot be other than a report of progress, and because of the great areas for which information is inadequate or lacking, they are likely to be much nearer the minimum than the maximum in terms of the total available resources. I believe the record of prior attempts of this kind, viewed in the light of subsequent mining history, will bear me out in this assertion.

At this point I would emphasize that in discussing the reserve situation of any given commodity, the rate of discovery relative to the rate of consumption is the significant and crucial test. No one knows how much of any given commodity exists in the crust of the earth, or how much may ultimately be found or needed; but we do or should know the trends in terms of consumption versus discovery, and if the ratio between these two factors are not maintained in favorable balance, trouble is bound to ensue.

There has been a tendency to blame the present-day shortage in many of our minerals and metals on excessive wartime withdrawals. The cold fact is, however, that today's shortages were hard upon us anyway. The inordinate demands of the war merely stepped up the rate of withdrawal, threw the problem into relief, and hastened the day of reckoning. But production was on the rise and the rate of discovery on the decline in a number of important commodities prior to the war.

That is my prepared statement, sir.

Senator MALONE. Mr. Bannerman, your last statement is very interesting to me, and, of course, absolutely true: that the rate of use of

the known supply of minerals compared to the rate of further discovery is the most important point. As I brought out, following Mr. Pehrson's testimony, that is one purpose of the work of this committee: to determine not only the available supplies but how further discovery can be accelerated. Do you think that the policies inaugurated by departments and carried out through the Congress and through the various organizations having to do with the regulation of mining, such as the Securities and Exchange Commission, are encouraging the investment of venture capital and further discovery?

Mr. BANNERMAN. I am not sufficiently familiar, Senator, with those policies or their administration to answer that question. I do know, however, that without venture capital we are not likely to retrieve our fortunes in this field because mine development is a hazardous business.

Senator MALONE. You do agree with me then, in line with the last statement you have just made, that mining does not become a business until the ore is blocked out?

Mr. BANNERMAN. Correct.

Senator MALONE. That it is a hazardous business, that it is a speculative business—in fact, approaches a gambling business until you have supplies of blocked-out ore through drilling operation or tunneling or types of exploration work.

Mr. BANNERMAN. Yes, sir. It takes a great deal of courage and optimism to put a mine into production.

Senator MALONE. There is another general statement that I will make, although I have been in the engineering business myself. Engineers rarely discover mines. They turn them down; isn't that right?

Mr. BANNERMAN. It depends upon the engineer.

Senator MALONE. That would be so of one who maintains a good reputation and has few failures. Isn't the policy generally to be very conservative?

Mr. BANNERMAN. I think I indicated my ideas on that when I spoke about the estimates embodied in the mineral-resource report. Engineers and geologists are inclined to be conservative.

Senator MALONE. Doesn't it devolve upon the prospector and the wildcatter and the men who are willing to venture their capital by contributing to the operations of these people; isn't that the way we find new mining fields and new oil fields?

Mr. BANNERMAN. If you will extend the term "prospector" to include the scientists and technologists who I feel must come into the picture from here on out I will agree. I think the petroleum industry is a good example of what can be done with systematic prospecting by a highly efficient, well-organized industry. But there must also be a profit incentive to go ahead.

Senator MALONE. Is it not a fact that we were practically out of oil, according to all the geologists in the country about 15 years ago, more than 15 years ago, but that there was a period of about 15 years that the geologists were making very careful estimates as to how long the oil supplies would last? As a matter of fact, we were only utilizing a very small amount of oil at that time compared to what we do now. But isn't it a fact that they got it down to 5 or 6 or 7 years?

Mr. BANNERMAN. When I was in college we were supposed to have about 12 years' supply, and that was 25 years ago.

Senator MALONE. Isn't it a fact now that we have more reserves than we ever had in our history?

Mr. BANNERMAN. Reserve figures in this volume show this to be so, but we are using a great deal more, sir.

Senator MALONE. Well, isn't it a fact, then, as we brought out a while ago, that there are more oil reserves in oil shale, known deposits of oil shale than we have, you might say, known underground reserves?

Mr. BANNERMAN. It depends on your definition of "reserve."

Senator MALONE. Reserve for emergency purposes.

Mr. BANNERMAN. Reserve for emergency purposes, yes. The oil shale "reserve" for the present, as of today, is only a potential reserve.

Senator MALONE. But it is a reserve in case of war, or other emergency; it could be utilized?

Mr. BANNERMAN. Yes.

Senator MALONE. Haven't we found in the last few years that sometimes costs are very volatile?

Mr. BANNERMAN. Yes.

Senator MALONE. And undependable?

Mr. BANNERMAN. Right.

Senator MALONE. I agree with you to this extent, the new methods of geophysical mining and others are additional factors.

Mr. BANNERMAN. That is right. They are additional factors and I believe they are big ones or are likely to be—in fact, I think, Senator, if we look at the history of mining for the last 25 years we would find that the majority of the important discoveries have been made through very painstaking work—geologic, engineering, and metallurgical——

Senator MALONE. That would be very embarrassing to engineers if we were to go into detail as to the actual discoveries.

Mr. BANNERMAN. I am talking mainly about discoveries in known fields. Most of them are extensions. Nature was pretty kind, in that ore outcropped in the first place. For a long while the mining industry ran along on easy street as far as reserves were concerned. Their big job was to develop more and more markets. Comes a time, however, when they literally have to go underground. The oil industry reached that stage in the twenties. I think the mining industry is approaching it.

Senator MALONE. Didn't the oil industry just discover a new oil field by someone making a mistake and going down 12,000 feet rather than the usual five or six thousand?

Mr. BANNERMAN. That is part of the story.

Senator MALONE. Did they have any knowledge of that oil field being there?

Mr. BANNERMAN. Yes, generally their exploration is based on a good geological bet. There is a difference between just punching a hole and having a good geological bet.

Senator MALONE. I suppose you are familiar with the deep oil discovery in California and Texas?

Mr. BANNERMAN. I am not thoroughly familiar with it.

Senator MALONE. The geologists did not predict it; it was not included in their supply at all.

Mr. BANNERMAN. It probably did not appear in the direct record any more than it usually appears. For example take potash, as far as

I know the first case in which the Government of the United States actually appropriated money to make definite explorations for minerals was in 1912. The purpose was to explore for potash. It took 20 years to get the geological background that was necessary to give sufficient meaning to the wildcat discovery made at Carlsbad in 1926, to warrant risk capital to step in and develop the potash deposits. The geological contribution is often forgotten, however, in reciting the history of that discovery.

Senator MALONE. You understand that I thoroughly agree with you that all of these are factors, but was the deep oil well considered to be a good bet?

Mr. BANNERMAN. Probably not; I don't know.

Senator MALONE. It was a wildcat.

Mr. BANNERMAN. I agree with you it was a wildcat at that stage.

Senator MALONE. I wanted to bring out the next point regarding policies and principles inaugurated by the departments charged with the regulation of these industries, that anything underground is a very indefinite thing, that it is not a business until you have blocked it out or you have struck the oil veins. Then any regulation makes it difficult and puts it into a business category.

Mr. BANNERMAN. Would you kindly repeat that?

Senator MALONE. I would say that any regulations by any department which would put it into the category of a business, before such time as the oil is discovered in that particular field, would retard venture capital, retire investment of such capital.

Mr. BANNERMAN. I am not sure I understand the import of your question, sir, as to what you mean by putting it into a business category. If your expectation——

Senator MALONE (interposing). I am speaking of income taxes, of Securities and Exchange regulations that make you conform to certain principles of business—that is to say, if any stock is sold and the mine runs out of ore——

Mr. BANNERMAN. Yes.

Senator MALONE (continuing). It endangers the men that sold stock.

Mr. BANNERMAN. In my use of the word "reserve," it is not a reserve, it has no value until it is shown to be amenable to commerce.

Senator MALONE. In other words, it is speculative money.

Mr. BANNERMAN. It is speculative money.

Senator MALONE. Do you have any further statement?

Mr. BANNERMAN. No.

Senator MALONE. We thank you very much, Mr. Bannerman.

I think your testimony has been of great value to the committee.

It is now approximately 12 o'clock, and the Senate will be in session in a few minutes. I regret, Mr. Miller, and Dr. Boyd, that we have not gotten around to you yet. We will tentatively set Monday morning at 10 o'clock, and we will recess until then. If there is any change due to conflicts you will be notified, and I hope, Dr. Boyd, and Mr. Miller, and the others that have so kindly stayed with us here for the 2 days, will be here at that time.

Mr. MILLER. I will be very glad to come back Monday morning at 10 o'clock.

(Whereupon, at 12 noon, the subcommittee adjourned until 10 a. m., Monday, May 19, 1947.)

INVESTIGATION OF NATURAL RESOURCES

TUESDAY, MAY 20, 1947

United States Senate,
National Resources Economics Subcommittee
of the Committee on Public Lands,
Washington, D. C.

The subcommittee met, pursuant to adjournment, at 10:10 a. m., in room 224, Senate Office Building, Senator George W. Malone presiding.

Present: Senators Malone (presiding) and McFarland.

Senator Malone. The committee will be in order. The hearing this morning is a continuation of the data submitted by the Bureau of Mines, and our first witness is Mr. James Boyd, of the Bureau of Mines.

STATEMENT OF JAMES BOYD, SPECIAL ASSISTANT TO THE SECRETARY OF THE INTERIOR

Mr. Boyd. Mr. Chairman, my name is James Boyd. I am not connected with the Bureau of Mines. I am special assistant to the Secretary of the Interior. My nomination is in but it has not yet been approved by the Senate.

I have no prepared statement, but there are one or two things that perhaps after hearing the testimony of the previous witnesses it might be helpful if I gave you some of my own thoughts.

Senator Malone. Dr. Boyd, I hope you will proceed in your own way and tell us the situation in any way you like for the benefit of the record. I think it will be very helpful.

Mr. Boyd. There is one thing I think the committee has seen since the Bureau of Mines and the Geological Survey have been here, and that is the inseparability of the program of those agencies. Although their work is entirely different in approach, the programs are inseparable in the development, control, and conservation of our national resources. From the conditions that we have developed from the reports which have been presented to you, it is apparent that the work of this committee is of primary importance to the economy of the United States in improving and maintaining the standard of living of the country itself, and maintaining the strength of the economy which will support these diplomatic operations we are now carrying on overseas.

The work of the Bureau of Mines and the Geological Survey is revenue-producing for the Government, generally indirectly, but I think you will see in some of these reports that the work of conserva-

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tion alone will bring to the surface resources which would not otherwise be produced, bringing new things, new wealth, to the Nation which, without the work of these technical bureaus, would never come to light and would never be added to our national wealth.

The important thing about the work of the bureaus in their relation to your committee is the fact that we must know what we are doing; we must have knowledge of all the background before we come to the conclusions which the Congress must come to in establishing a national resource policy. To do that we must have a firm statistical background. You know the position statisticians are put in but nevertheless they are indispensable in policy making.

It is also important that we have channels of intelligence, not necessarily in terms of specific statistics, but through the general knowledge of trends which can be developed only in the minds of individuals who are familiar with and have the technical background to do that work so that they can come in to you after making their observations and keep your committee currently informed. I should like to consider those people as supplements to your own staff, because they can give you the help that you need. They are trained to develop the programs you need to act upon. To do this, they must maintain constant contact with the industry which serves the economy of the United States in providing the raw materials necessary to it. That is done in the daily work of both the Survey and the Bureau of Mines, in that their field representatives are in constant daily contact with the industry itself. They do that by personal relationships and by establishing a confidence which permits the industry to talk freely to them, knowing that their confidence will not be violated, and it strengthens the position and the knowledge of these men that you will be calling upon for advice.

In the determination of the line of action, thorough knowledge of the field is, of course, most essential. It means the development of programs within the technical bureaus, insofar as they have their effect upon the program established and the policies developed by Congress. The carrying out of those policies is done by the technical bureaus in their encouragement of research, in their own efforts and in the work of industry itself. They provide a measure of leadership, a rallying point where the various phases of industry can be coordinated and strengthened. The industry itself must improve our production of materials.

The two main problems to me are, first, the strengthening of the basic resource production within our own borders, so that they may strengthen industry itself, and then the provision for our national security. Conservation is an important pertinent part of those policies. It means the means and methods for utilizing all the available resources and seeing that they are not lost by improper development and production or lost due to adverse economic conditions.

The forward-looking actions of the Bureau and the Geological Survey provide the background from which the industry can take up the work when the economic conditions become favorable. I think you have seen from the testimony of Mr. Ralston, which he presented at the last meeting, that these scientists will spend many long years of study before they develop an idea. Before industry itself could handle it, the economics of the situation will not permit the industry to take up

the problem in the very early stages. I think probably the outstanding example of that is the work done by the Bureau of Mines for many, many years on the treatment of low-grade iron deposits. That work was carried on under very discouraging circumstances. The industry was not ready to take it up because they had sufficient high-grade ores, and it was not of great interest to them. Economically they could not undertake it. Today industry is rapidly taking over that operation from a much more advanced point than would have been the case had not the Bureau had the foresight to lay the foundation years ago. You still have the Bureau of Mines as a rallying point and I suppose it will not be very long until they will be able to leave that work entirely to industry.

In the short period that I have been in Washington this trip, I have been impressed tremendously with the complexity of the operations of government in the development of our international policies and the necessity of taking into consideration the resources of our Nation—our internal mineral-resources problems. As you know, the various departments of government are constantly working on the problems, particularly now that we have attained leadership in the United Nations, where they are working with the United Nations in developing programs and policies to recommend to the various member countries. Those policies will many times come to you more or less "fait accompli," meaning that you will get policies developed for you that will be hard to change unless you are kept informed as they develop. That means the Interior Department should have a staff which will be able to keep contact with policy development and keep you informed of their progress.

The appropriations—I think Mr. Miller will talk about this more in detail—but there is some danger that the staff that would carry on that work will be eliminated under the present appropriation.

I think that is about all I have to say in a general way. I have not been here long enough to know the details.

Senator MALONE. Dr. Boyd, the committee will be very glad to receive your statement, and particularly to know that the work of the Bureau of Mines, the United States Geological Survey, and other divisions of the Interior Department, will be available to us. I knew they would be, but your assurance of full cooperation is very helpful.

I was going to ask you—this is a little beside the subject, but still in line with the metallurgical development—there has been some criticism of the Bureau in times past about the methods worked out by the Bureau in metallurgical experiments on which patents in times past apparently went into the hands of private individuals. What is the policy of the Bureau now, or the Department of the Interior, in the matter of new processes and patents? Are they all retained now by the Department of the Interior or the Bureau of Mines—any new patents as a result of your metallurgical work or experiments?

Mr. BOYD. I think I would rather refer that question to Mr. Miller. I don't know.

Senator MALONE. You agree with the general objectives of the committee then, I take it, Dr. Boyd, in that you are suggesting a corresponding course in the minerals and materials field, first, of course, the objective of national security, and then maintenance of our stand-

ard of living in the designing and production of these materials and minerals, creating employment and additional taxable property for the country, and other secondary considerations, making it as nearly self-sufficient as we can in these fields.

Mr. Boyd. I think that certainly should be the objective from a security point of view, coming as close to self-sufficiency in our own mineral industries as we can. That is the first prerequisite to a strengthened industry. That has been the basis of our strength throughout our history, and although there are many minerals which we do not have at all under present economic conditions because they do not exist in our territory, in the long run they are dollarwise quite small in proportion in the entire mineral industry but extremely important to us.

Senator Malone. In that connection, then, the chief work of the Bureau of Mines and the United States Geological Survey is to work out new methods through metallurgical experiments and mapping of the less known areas and geological work, all of which is available to any citizen of the United States who cares to invest his money and time attempting to discover and develop these minerals.

Mr. Boyd. That is right.

Senator Malone. I believe that in the field of the entire development of our national resources the minerals field is a very important field. As was stated earlier in the hearing, the production of minerals, I think in 1946, was 9 billion dollars; for agriculture, 23.9 billion dollars, which covers a much broader field. That is a very important economic field for the country. It is important for the economic structure of the country. That is the reason I am glad to hear you stress that part of it in addition to national security.

Mr. Boyd. I might add there, Senator, that the actual basis of agriculture is fertilizer, which is also in the mineral field.

Senator Malone. That is true, and very important.

Now, as regards these lower-grade iron ores that you speak of, there are some ferrohydrate iron ores that are well known in the country but have been a little difficult to work on account of the foreign substances included in the iron ore, such as sulfur, phosphorus, and various ingredients. The Department has been working on that angle of the problem, has it not?

Mr. Boyd. I understand they have, yes.

Senator Malone. And we do have an enormous amount of iron ore. It is a question of grade and the presence of foreign substances that make it hard to use.

Mr. Boyd. That is right. It is interesting to note in that connection, Senator, that many of the European iron industries have been dependent for many years on ores of grade equal to or lower than these that we now talk about as our future reserve.

Senator Malone. That is a very important point, especially since—and I suppose you have noticed it over the years—every once in a while there is a magazine article setting forth the idea that the Mesabi range ores have a definite limit, and indicating that we are about out of iron ore. You remember such articles over the years?

Mr. Boyd. Yes, I have seen those statements.

Senator Malone. They are very perturbing to anyone who understands the situation, and are often written, I have been of the opinion,

and still am, to put over some other points that will come later, like the importation of iron ore or some other substances that are needed. In other words, we are not short of iron ore. We are short of high-grade, pure iron ore. Is that about right?

Mr. BOYD. We will be in the future.

Senator MALONE. We are not now, even of that type of ore?

Mr. BOYD. That is right.

Senator MALONE. And perhaps in the foreseeable future will not be out of iron ore, as you so ably have said, of a grade that most of the foreign nations consider they have a complete monopoly of.

Mr. BOYD. Yes. In that connection, Senator, I am pointing out these things that I think must be pointed out, because, as we change the basis of our natural resources, we have got to change our methods for the production of them. I mean the change in economy, the economic structure of the country, so that it is well to keep constantly in people's minds the necessity of recognizing these changes.

Senator MALONE. I agree entirely with you, Dr. Boyd, that we must be informed, but not be scared that we are running out of ores.

Mr. BOYD. That is right.

Senator MALONE. The technologists in the steel industry themselves, of course, are helping to develop processes, too, and are fully aware of these facts.

Take, for example, manganese, high-grade manganese, from which is made the ferromanganese which is used in the steel industry. I am informed that it is entirely possible to use the pure manganese metal in the manufacture of steel; and manganese metal, as Mr. Ralston so ably testified, is rather plentiful, through the electrolytic process worked out by your own bureau in your pilot plants at Boulder Dam and in the South. But there again it does entail a change in the process of manufacturing steel. Is that true?

Mr. BOYD. That is true. And also the changed economics, to some extent.

Senator MALONE. But we do have manganese for steel at a slightly higher cost.

Mr. BOYD. That is right.

Senator MALONE. Those are important points, because the committee in the long run not only wants to get the information from the Bureau of Mines and the United States Geological Survey as to minerals, but we want to pursue this through the field of agriculture and forestry products, to show exactly the same thing, not only where we can compete economically but where we can be self-sufficient, even at a slightly higher cost. And, of course, then, when we get this information, our next question is: What is the difference between the cost of the imported article and the article here, the mineral or the material? Then the Congress of the United States and the executive departments can start working out a policy and see how near we want to keep self-sufficient, even at higher cost, considering our higher standard of living and the higher wages in the country. That is the last thing, and all of this is laying the foundation for it. Do you agree that is the way to go about it?

Mr. BOYD. I think it is; yes, sir.

Senator MALONE. That is the only way I know.

Mr. BOYD. I agree with you on that.

Senator MALONE. Does your Department have, or are you familiar with, the information on foreign deposits in the various countries of these minerals that we speak of, more particularly the 39 minerals that your Bureau has filed a very complete domestic report upon—Do you have sufficient information on the foreign deposits or the ability of certain foreign countries to produce these minerals?

Mr. BOYD. We have some information, Senator, but good information is sadly lacking. It needs strengthening—this is a question I talked to you about before—it needs strengthening because we must know what is going on in other countries. To act intelligently, we must have full knowledge of conditions here and abroad. Other countries do not, as a rule, supply the same kind of statistics that we supply to the public in this country. As a result, we are sadly deficient in our knowledge of what is going on in foreign countries, what is available, and what problems will arise in that connection.

Senator MALONE. Is this information available to us if we went to work on it? What would it require in order to get fuller information on the situation?

Mr. BOYD. The principal thing required, sir, is establishment of mineral attachés in the embassies, in our embassies in foreign countries, people who know what to look for and will keep their eyes open, keep supplying us with the information which can be made available to your committee and to the public here. Our own industries need that information. There are some metals, particularly these items which we do not have in this country, the rarer metals, things that are rare to us—the industry must know what is going on. A private company could not maintain the intelligence sources abroad that they need in order to know what is going on, what is being discovered, what the production is, and what it is likely to be. For the support of the entire industry it is most essential that the mineral industries have that information so they can maintain their supplies to the manufacturing industries.

Senator MALONE. The interest in that matter would be twofold for this committee. First, regarding minerals and materials that it is, generally speaking, shown we could not produce. This committee would be very much interested in those, because I presume you agree that is where our stock piles would come in.

Mr. BOYD. In large measure our stock piles in those metals which we do not have must come from foreign countries. And that is for national security.

Senator MALONE. Then it would be interesting, would it not, to have some information as to the quantities of these materials in these other countries, where they are most plentiful, and the cost of foreign production compared with the cost of producing these materials here?

Mr. BOYD. That is right. It is also necessary to know the policies of the foreign countries and how they are going about the development of minerals, to be sure that we have a supply of them to maintain our stock-pile program and also our industry itself.

Senator MALONE. Is that part of your program? To the best of your ability are you now working on it?

Mr. BOYD. As I understand it, the Bureau of Mines included in their request for appropriations a certain sum of money—I don't know

exactly how much it was—for that activity. A large part of that, I believe, was eliminated by the action of the House.

Senator MALONE. If the Bureau can answer the question, or if any witness here is able to answer it, I hope you will; if not, I hope you will get that information and submit it for the record.

Dr. Boyd, we appreciate your appearance before the committee, and I know that the members of the committee will consider your testimony very helpful. Do you have anything further to offer?

Mr. BOYD. No, Senator; I have nothing further.

Senator MALONE. Now we will hear Mr. Tom Miller, Assistant Director of the Bureau of Mines.

STATEMENT OF THOMAS H. MILLER, ASSISTANT DIRECTOR, BUREAU OF MINES, DEPARTMENT OF THE INTERIOR

Mr. MILLER. I do not have a formal statement, Senator Malone, but I would like to talk briefly on the general subject of foreign minerals if I may.

Senator MALONE. Proceed in your own way, Mr. Miller.

Mr. MILLER. This has been discussed somewhat already this morning, also mentioned briefly in the previous hearings both on Thursday and Friday last.

As I recall, at the Thursday morning hearing when the Secretary was testifying, there were questions along that general line asking the Department to emphasize some of the things it was doing during the war, but which it had been forced to stop since the war. This activity would not be one that would be covered in that. This activity was largely conducted by other agencies during the war, not by the Interior Department, and I think we all remember that rather hectic period in the early part of the defense days before we actually were in the war—the confusion that existed in establishing an agency or an organization to start assembling information on foreign minerals which was not available. A new organization had to be developed to make it available. The entire procurement program for defense and all of the policies regarding procurement and preclusive buying had to be evolved from information not then available.

Senator MALONE. At that point, Mr. Miller, what became of the records of the old War Production Board, where they had a specialist or a corps of specialists on each mineral? As a matter of fact, I worked with them some as special consultant to the Military Affairs Committee of the Senate, and I used to work with various sections down there on those records. The Seventy-ninth Congress passed a law—I believe Public 728, but I will have to check that—which required the agencies to transfer to the Bureau of Mines—rather, to the Interior Department—that information which had to do with domestic minerals which they had accumulated during their war existence. What about that?

Mr. MILLER. Unfortunately, that bill did not mention foreign minerals at all. It was limited specifically to domestic minerals. The War Production Board itself had less information on foreign minerals than the Foreign Economic Administration, FEA, which was the agency in which most of that information was centered.

Senator MALONE. What was that?

Mr. MILLER. The Foreign Economic Administration. Their records were divided when FEA was dissolved. Part of the records were turned over to the Reconstruction Finance Corporation and part to the Department of Commerce. We hope ultimately—in fact, we have taken steps now to try to obtain some of those records.

Senator MALONE. Do you know how they were divided?

Mr. MILLER. That portion which had to do with the U. S. Commercial Company activities, the RFC subsidiary which handled foreign purchases, and that proportion of the record of FEA which had to do with those contracts, was transferred to RFC.

Senator MALONE. Which had to do with the contracts that RFC had made with commercial companies?

Mr. MILLER. No; the contracts that the U. S. Commercial Company itself had made with foreign suppliers, which included all the mineral contracts. The bulk of the records that we were concerned with were transferred to RFC. The rest of the records had to do with things other than minerals, and were mostly transferred to the Department of Commerce.

Senator MALONE. Will you repeat for the benefit of the record, just what the Department of Commerce received?

Mr. MILLER. As I understand it—now I am not too famiilar with the record, but the Department of Commerce received those functions and records which had to do with most of the procurement of things other than minerals from foreign sources.

Senator MALONE. Materials?

Mr. MILLER. Yes. The U. S. Commercial Company was the agency which handled all of our foreign contracts for minerals, and most of that record was transferred to RFC. We are now negotiating with the Reconstruction Finance Corporation to obtain not only that record but other mineral records also.

Senator MALONE. Those records are supposed to be complete as left by the War Production Board, and they are all in existence?

Mr. MILLER. We feel that that is a very excellent file and we are anxious to have it. We think it is very important that it be preserved.

Senator MALONE. I know it was an excellent file in the divisions that I worked with.

Mr. MILLER. Unfortunately, Public Law 728 of the last Congress would not directly cover information on foreign minerals. It would by inference but not directly. However, we have not met any particular resistance on the part of RFC in ultimately transferring that record to us. They asked that they keep it for awhile, but I believe ultimately the Bureau of Mines will get it.

Senator MALONE. That is merely a voluntary agreement between the two bureaus?

Mr. MILLER. Yes. RFC, of course, has some rather rigid rules of their own in their own corporate structure for the disposal of records. By law they have to retain them for a certain number of years—6 years I think; sort of a statute of limitations—after the contract is dormant.

Senator MALONE. In the meantime, are these records available to you?

Mr. MILLER. Yes; they are.

Senator MALONE. You can get them?

Mr. MILLER. Yes; we are able to view them, and in a few instances we have made photostatic copies of some of the information we needed.

Senator MALONE. They allow you to make photostatic copies?

Mr. MILLER. Yes. It has to be done in their shop under their supervision, but we are permitted to view the record.

Senator MALONE. What about the Department of Commerce?

Mr. MILLER. That record that went to the Department of Commerce, I believe Interior would not have any particular concern with. It did not have much to do with minerals. It had to do with things like rubber or silk or cork—things of that nature—not so much in the mineral field. The record that we are mostly concerned with is the purchase contracts of the U. S. Commercial Company and the background files in connection with those purchases.

Senator MALONE. Go right ahead now, Mr. Miller.

Mr. MILLER. The Bureau of Mines recognized some 3 years ago that the Foreign Economic Administration would not be a permanent Government agency; that ultimately it would be dissolved, and at that time we undertook to get written into our appropriation structure funds to establish a small group in the Foreign Minerals Division of the Bureau of Mines which would slowly take over and continue the essential functions.

Senator MALONE. Is the Foreign Economic Administration in existence at this time?

Mr. MILLER. It is not. It dissolved approximately a year ago. I will have to check the date, but it was about a year ago.

Senator MALONE. Right at that point, there were some newspaper reports at the time, that these records were being placed in the Archives. Would that have to do with any of these records? By "Archives" I mean the last repository of the Government for useless records.

Mr. MILLER. It is conceivable that some of that record did go to Archives. I am not sufficiently familiar to give a positive answer to that.

Senator MALONE. Could you find out about that?

Mr. MILLER. I can look into that and insert the information in the record to bring it up to date. We do have, of course, access to the records in the Archives, either by microfilm or direct study. They have microfilm service. We pay for the microfilming, and they run off anything they have for us.

The Bureau of Mines has been advised by a representative of the National Archives that although a large part of the FEA records have been transferred to Archives, it is their understanding that FEA records having to do with minerals have been sent to the Reconstruction Finance Corporation. It is believed, however, that some of the foreign minerals records may have been acquired by other agencies and some difficulty may be encountered in assembling all the records into a single file.

Going back to the history of the Bureau's activity in regard to foreign minerals, I would say that 3 years ago we attempted to get our appropriation so organized as to reflect the need for that type of work and to have money made available. It was to be done in cooperation with the State Department, the theory being that any foreign activity

that we would undertake would have to have the clearance of the local ambassador or minister in charge.

Senator MALONE. Right at that point, Mr. Miller, if you have full access to the RFC records and to the Archives, or, better yet, if all this material were to be transferred to you, wouldn't that obviate the necessity for a lot of work that you would normally have to do?

Mr. MILLER. It would certainly save us having to repeat a tremendous amount of work, but it would not obviate the necessity of assembling current information.

Senator MALONE. Do you agree with me that that was a very complete record at the time the war ended?

Mr. MILLER. I agree completely, Senator.

Senator MALONE. Then it would only be a year and a half out of date.

Mr. MILLER. Yes, sir.

Senator MALONE. And you would also have the sources of information, and the necessary contacts could very easily be reestablished, I believe, based on that record.

Mr. MILLER. Congress 2 years ago denied funds for the expanded foreign minerals program, but last year they did appropriate funds to the State Department for that type of activity, but failed to match that with the corresponding money necessary for the Bureau of Mines.

Senator MALONE. Just what activity do you mean in the State Department?

Mr. MILLER. I am referring now to Public Law 724 of the Seventy-ninth Congress, approved November 13, 1946. In that law the Congress established and provided for coordination of foreign activities by various Government departments operating through the State Department—in other words, the Department of Commerce, the Department of Agriculture, the Department of the Interior—any agency having need for foreign information could then establish coordinated programs with the State Department and get their mineral experts or their technical experts appointed to the Foreign Service of the State Department. Obviously the need for splitting the money was that while the individuals were actually abroad on a foreign assignment, they would be on the State Department pay roll, and while they were in this country they would be on the pay roll of the Department of the Interior, actually running about 1 in 3; that is, for every $3 appropriated for the State Department for this work we wanted $1 appropriated for the Bureau of Mines.

Again in the 1948 estimates we inserted requests for similar funds. We had asked for $151,640 in our Foreign Minerals Division. That was reduced by the House bill. Although the House bill language is a little unclear and we don't know the precise distribution of the funds appropriated, it is about $75,000 as near as it can be estimated. We have asked the Senate to restore the $76,640.

Senator MALONE. What do you consider the minimum that you could get along with if these records of the Reconstruction Finance Corporation were entirely at your disposal or turned over to you?

Mr. MILLER. To turn over such a record at this time would require at least a temporary expansion of our Washington staff to assemble and prepare that record for our use. The records would have to be reorganized and studied. Following that there would be the establishment of foreign minerals reporting officers themselves, mineral attachés

to be attached to the various embassies around the world in the areas which are the principal sources of supply of the minerals with which we are concerned. I would not be able to give you an exact figure as to how much of a program we would develop.

Senator MALONE. The idea would be to put a man in the foreign nation itself in our American Embassy.

Mr. MILLER. Yes; we would recruit or take someone from our own staff, a trained minerals specialist, and assign him to the State Department. The State Department would then attach him to the consulate or the ministry or the ambassador's office in whatever country it was determined he would go.

Senator MALONE. Do you know whether or not the State Department has such a man at this time, having in mind the appropriation that was made for them to get such information?

Mr. MILLER. At one time the Bureau had seven such offices.

Senator MALONE. That is, the State Department did?

Mr. MILLER. Bureau of Mines people on the State Department pay roll, mineral attachés of the Bureau of Mines attached to the State Department and assigned to foreign governments.

Senator MALONE. Do they now have any such men?

Mr. MILLER. At the present time only three. We have not been able to replace vacancies. At the present time we have one in Peru, one in Brazil, one in South Africa, only three mineral attachés now on the work. Our hope is to be able to expand that service very substantially.

Senator MALONE. Have you made a study to know about how many countries would need such a representative to do a first-class job?

Mr. MILLER. The program envisioned in this appropriation would permit the ultimate establishment of between 25 and 30 such field offices, depending somewhat on the cost of doing business. We do not know how much it is going to cost to maintain reporting offices.

Senator MALONE. Supposing these records were made available to you, not only RFC, records but records to be found anywhere that apply to your program, then would the $75,000 be enough for a staff here to correlate those records and get them in shape for the coming year?

Mr. MILLER. Not the money that is left in the House version of the bill. The present staff, working on projects other than the program that we are speaking of here this morning, requires very nearly that amount of money to do the things which we are now doing in our Foreign Minerals Division. In other words, we are still running the round-up of such statistical information as is available, and the general assembling of such information as can be made available without having to have field engineer offices getting it.

Senator MALONE. You do not have field engineers at this time, but can only correlate such information as you would get from the RFC and other agencies, if that information were made available to you. Could you in the next 8 or 10 months correlate this information and be ready then for the foreign extension with the money those agencies are now getting?

Mr. MILLER. With the money now in the House bill? I would have to examine that. I don't think I could give an answer this morning. To do so without additional funds would require giving up some work now being done in the Division.

Senator MALONE. Would you do that for the committee and have it appear as part of your testimony? And if you do have to have an additional amount over the $75,000 for that particular work, would you make that part of your testimony?

Mr. MILLER. Yes; I will be glad to develop an alternative plan.

(The information requested is furnished herewith:)

Assuming that the foreign minerals records now held by the RFC and other agencies are made available to the Bureau of Mines, it would be possible for the Bureau to do much of the work of assembling and correlating such information with the funds expected to be available for the fiscal year 1948. This can only be accomplished however, at the expense of discontinuing or reducing other activities of lesser importance. It is believed that a start must be made on this work as soon as possible in order to prevent the possible loss of records as are now available.

Senator MALONE. This is the reason I am asking that: If we are looking to the future, perhaps it would take us some time to get ready to get the information ready for use, and even if you did not get the money until next year to expand as you would like to and probably properly should, it might not be available until we could get ready for it. I have that in mind.

Mr. MILLER. We had not anticipated expending immediately to the full level. This type of project would develop very slowly. On the other hand, there are subjects and areas for which we could find people to do almost immediately if we had the funds. For example, we have been working very closely with the newly organized Central Intelligence Group in the joint Army and Navy activities on securing intelligence. They will probably assign to the Interior Department the bulk of the responsibility for collecting and interpreting information on foreign minerals. They need a great deal more information on foreign industrial activities, including minerals, than we would be able to provide at this time, therefore it would be a question of selecting what areas and what subjects to deal with. We would select the most important of the critical minerals and the most important of the critical areas and concentrate our activities within that framework as a starting point.

Senator MALONE. Do you have in mind particularly the Army and Navy Munitions Board?

Mr. MILLER. Well, it is coordinated with the Army and Navy Munitions Board. Actually it is an independent board called the Central Intelligence Group, a consolidation of the G–2 and A–2, and a number of other functions in the military intelligence of both Army, Navy, and Air Force.

Senator MALONE. Do you work closely with the Army and Navy Munitions Board, and are you familiar with the information they have?

Mr. MILLER. Yes; a good many of our staff are members of various subcommittees of the Army and Navy Munitions Board, and are very active in that whole organization.

Senator MALONE. Members of that staff are appearing before the committee, and we may get further information that will be useful. Our idea is to try to coordinate the work—that is, this committee is not going to coordinate the work of your bureaus but find out what would be necessary in making available to all of your organization the information they really need for security.

Mr. MILLER. That is essentially what we tried to do, working with both the Army and Navy and the Army and Navy Munitions Board.

Our basic problem here, of course, is the realization that it is not sufficient to assume that because we cannot produce enough of any mineral in this country we will be able to import it. We have to have some assurance that we will be able to import material, and in order to protect this Nation, both from the standpoint of military security and its normal commercial relationships, the Government and the public generally are going to need more information about what areas of the world can produce minerals in which we are deficient in the United States. Cursory examinations of rates of production and use elsewhere indicate that there are very serious problems. As an example I might cite lead, which is generally in short supply on a world-wide basis. The sources of lead are believed to be inadequate to meet present world demands unless new discoveries are made. If we cannot produce enough lead in this country we will have to import it from areas where we are going to be buying in competition with other nations also trying to import that same material, and as other nations become more and more nationalistic in their own viewpoint toward self-sufficiency, it will become progressively more difficult for us to obtain those supplies for stock-pile purposes. Our commercial interest will be confronted with the same problem.

Senator MALONE. Mr. Miller, what percentage of our domestic consumption of lead do we produce?

Mr. MILLER. Prior to the war, during periods of low demand, we were virtually self-sufficient in lead for many years. During and since World War II, however, we have depended more heavily on foreign imports. In recent years total consumption of primary and secondary lead has slightly exceeded 1,000,000 tons a year, roughly one-third each from domestic mines, scrap, and imports.

Senator MALONE. Probably on account of costs as much as anything?

Mr. MILLER. A combination of lower cost of production elsewhere, plus the deficiency in known reserve capacity in this country.

We have discussed this rather thoroughly now, and perhaps it might be appropriate to enter this statement in the record at this time. This is a statement on the general line-up of the foreign mineral problem.

Senator MALONE. It will be placed in the record at this point.

(The paper referred to follows:)

(f) *Foreign Minerals Division.*—The tremendous importance of minerals in international affairs, the growing dependence of the United States on foreign sources of supply for certain minerals, the stock-piling program and other national-defense planning activities, as well as the importance of foreign markets to some of our mineral industries that produce in excess of our requirements, emphasize the need for expanding the Government's fact finding on foreign mineral developments. Before the war, factilities for this purpose were grossly inadequate as a result of which there was a serious lack of first-hand data on enemy mineral potentials and the availability of foreign materials to meet the tremendously increased domestic demand for minerals in the defense and war programs. Procurement was delayed, and there was a rush to obtain the needed basic data with which such purchasing as well as preclusive buying and the good-neighbor programs could be planned and executed. Staffs of technical experts were qiuckly recruited in the various war agencies responsible for these activities and sent abroad to centers of production of strategic and critical minerals. The effort was extremely costly and inefficient, an inescapable consequence of the lack of preparedness in this field.

The need for improvement in this type of activity has been recognized by the House Committee on Military Affairs in House Report 2734 of December 17, 1946. In Public Law 724, Seventy-ninth Congress, approved November 13, 1946, Congress has provided for cooperation between the Department of State and the technical agencies of the Government to facilitate the temporary assignment of technical experts to the Foreign Service. By this means the Government will greatly improve its technical and economic intelligence services. For its part of the program the Bureau proposes to provide a small staff of regional and international commodity specialists who will make first-hand observations abroad from time to time and provide Congress, the Army and Navy Munitions Board, the Central Intelligence Authority, the State Department, and other agencies of the Government, as well as industry and the general public, with essential information on foreign minerals. The House committee has eliminated most of the increase that was requested to initiate this important activity.

Mr. MILLER. That is all I have in general on the foreign minerals program. I would like to mention briefly that basic statistical information is the beginning point for most studies of this kind, and the Bureau should have rather complete latitude, I think, in selecting the kinds and types of statistics which should be collected. I believe that we should have a balanced program, not eliminating any one field and concentrating entirely on some other field. That again brings up the question of limitations in the language of the House Appropriations bill, which specifically precluded our doing any statistical work on bituminous coal. The way the bill now reads we would not be able to do any work on production or consumption of bituminous coal. We feel not only that there is a great need for statistics on production and use of coal, but also that we have been seriously restricted in our ability to divide the money appropriated between essential fields of activity.

That is all I have in the way of a general statement, Mr. Chairman. If you have questions, I will be glad to answer them if I can.

Senator MALONE. Just what is that limitation for. Is it because we were so self-sufficient in the production of coal that it was considered unnecessary?

Mr. MILLER. The committee apparently took the position that the information was primarily for the use of industry, and that they should pay the cost rather than the Federal Government?

Senator MALONE. And that bituminous coal was not a problem of shortage?

Mr. MILLER. The committee report stated that the information was primarily for their use, and therefore let the industry pay for it. There are many reasons why we feel that the Federal Government and the public generally have great need for such information.

In the first place, the coal industry is a huge operation spread broadly all over the United States, a large number of units, both large and small, and it is very difficult for even a Government agency to collect adequate information. I think it would be virtually impossible for a private industry to collect the information that we feel is basically necessary to fill the needs of this Government and the public generally, as well as those of the producers themselves.

Senator MALONE. I note that in your chart dealing with the lead situation, you show, as you say, that we are very nearly self-sufficient all the time, and at times during the war years a little above in the production of lead. I also note that the price apparently is related to the amount of lead produced. When it is up in price the production goes up sharply. Now, we do have another organization, the

Office of Price Premium Plan, dealing particularly with copper, lead and zinc, which will appear before the committee. We can ascertain then what premiums were paid in addition to the normal price. We hope that will be some key to the amount of production that can be expected.

Mr. Miller, at this point, too, I think there is a little general misunderstanding on the part of the public, and I am sure there is in the minds of the Members of Congress who are not in areas dealing particularly with minerals, as to what tariff and import fees and various devices of raising the price of minerals are used.

(At this point Senator McFarland took the Chair.)

Senator McFarland, Mr. Tom Miller of the Bureau of Mines has testified to the general situation of minerals.

There is a misunderstanding on the part of the general public that a tariff or import fee precludes the importation of minerals, that it will not take place. Take, for example, tungsten. We all know that there is a 50-cents-per-pound tariff on tungsten. By virtue of that 50-cents-per-pound tariff we produced, up until the war years, the Second World War, approximately 45 percent of our domestic consumption. At any time when you raise the import fee or tariff you probably produce a greater percentage; when you lower it you will produce a lower percentage, because they get less for production, your chief competition being in China, where wages are 40 and 50 cents a day, whereas in this country they are $9 a day, and 50 cents per pound presumably makes up that differential in cost, considering the economies of production and freight and all that. But the tariff did not preclude imports, it simply kept us in business, so we had the know-how and the men in production and the companies in production, so that when the war years came along the new discoveries and the increased production gave an increase in price. As I remember it, the price in peacetime was about $16 a unit, and it went to $28.50 a unit, and at that price we became practically self-sufficient in the production of tungsten. There was great argument at the time it went to $35 whether we would continue self-sufficient in tungsten.

I mention that one particular mineral to show how the import tariff works, that it does not necessarily prohibit imports, but keeps us in business, and as one member of this committee I hope that as to these minerals we keep in business, we must keep in business for these three things I have mentioned; national security, employment, and providing taxable property. I have outlined here, Senator, that the purpose of this committee is to determine the availability of these minerals, and then what that differential cost is, and then the Congress of the United States will determine the policy that we should pursue. Do you agree with that, Mr. Miller?

Mr. Miller. I think that is quite right. The example you cited affords an excellent illustration of the purpose of the tariff originally. When the general tariff act of 1930 was passed, which did provide protective tariffs for a large number of minerals, it was for that very reason, equalizing costs between the higher wage level and the higher general level of living in the United States as against much lower labor cost in foreign nations. That is the basic philosophy of the tariff structure. Although the tariff structure generally has trended downward in recent years and may continue that way in

the future, my own personal view is that if there are to be further tariff changes they should be very gradual and not made abruptly over night, but gradually over a long period of years.

I strongly support the chairman's statement that we must maintain the mining industry in the United States in a healthy, vigorous condition, and if the tariff helps to do that, then I say that is the best type of protection we should have.

Senator McFarland. Have you completed your statement?

Mr. Miller. I have completed my statement, Senator, except for any questions that may be asked.

Senator McFarland. I was not here during your statement, so I do not believe I could ask any questions. We have had, at least in copper, lead, and zinc—some of the Senators like to kid me about that—we have had premiums as an incentive for the higher cost of mining, and to encourage also the development work. What do you think about that program in comparison with tariffs, or what do you think we ought to do about it?

Mr. Miller. Well, that is a very difficult question, Senator. As you know, the department has taken a position in opposition to continuation of the premium price structure as it is now developed, on the general ground that it is contrary to the normal American way of doing business, particularly as indicated in the mineral industry. That is not to say, however, that there should not be some Federal support of some sort to encourage exploration and development, of the type in the premium price plan. We felt however, that that was not the proper structure for doing it. One objection to the premium price plan is the fact that it was developed during the period when prices and wages and generally everything were under very strict control of various types and kinds. We are now moving away to a free economy without ceilings on price and with labor free, with no wage ceilings on labor and no restrictions on manpower, which make entirely different conditions under which this system will have to work.

The other point is that throughout the entire experience of the premium price plan there have been demands greater than the maximum production that could have been brought out under the premium. In other words, there never was a question of marketing the products. We are moving forward now into a period where the reverse may be true. We may at some future time have surplus production over and above the current needs, and the functioning of the subsidy system then, under those conditions, will be rather the reverse of that during the periods of shortage, when we are attempting to stimulate production. In other words, the more you stimulate under those conditions, the worse your subsidy program becomes, and the problem generally becomes worse. For example, if the supply of copper was adequate to meet our needs, every pound of copper that by subsidy was brought into the market would tend to depress the market, and gradually you would have to meet that situation by subsidy.

Senator McFarland. But of course, that cannot happen today.

Mr. Miller. Not in the immediate future. Nobody can guess exactly when it is likely to change over. Conceivably, however, the present terrific demand for those three metals, copper, lead, and zinc, may start easing off in the relatively near future, but not immediately.

Senator McFarland. I agree with you that the premium plan was

developed as a necessity to meet a war condition that grew up on account of the control of the price of copper, lead, and zinc. I think the price of copper was probably fixed too low. Before the war I used to say to Leon Henderson that if he would raise the price of copper, he would encourage a certain amount of production; that people in the mining business—naturally, it is partly the gamble in it that causes them to spend their money, and you can't just say that you are not going to allow more than 1 cent a pound increase in the price of copper, and say that that is enough, and expect to get maximum production of copper or get exploration work done in that field.

Mr. MILLER. Prices of copper, lead, and zinc gained sharply when a free market was reestablished. This would indicate that the OPA ceiling prices were too low.

Senator MCFARLAND. But it seems that we need some kind of a floor in this strategic-metals field anyway to encourage production and build up a stock pile, whatever premium it may take.

Mr. MILLER. The Department, of course, has given very serious thought to alternative methods of stimulation of that type, aside from the premium price plan. A number of things have been suggested, but I don't know that they offer any more hopeful solution of the problem than premiums and the subsidy system. It is conceivable that direct action on the part of this Government to relieve the local situation might help greatly. For example, if the water problem in any one district—for example, in the tri-State area—became a very serious drain on the resources of those operating companies, it is conceivable that the Federal Government might step in and say:

"We will defray the cost of pumping your water." Just like we did in the case of the Leadville district, where the Federal Government financed the building of the long drainage tunnel to relieve the cost of exploration by individual companies. Relief of that type is entirely conceivable, to my mind. I see no objection to that.

Senator MCFARLAND. I didn't want to draw you out into a particular discussion of the premium plan, but I take it from what you have said that you would prefer the tariff as a means of keeping wages up rather than the other method.

Mr. MILLER. I would say that the two things though relative are for different purposes. The basic purpose of the tariff was originally, and still is, that of equalizing the cost of production between United States producers and foreign producers in the same commodity, and the tariff structure is the policy that this Government has developed to meet that particular issue. A stimulant to encourage development and exploration and production over and above the tariff margin, to me presents an entirely different problem, not the same. In other words, they are not interchangeable one with the other, as I see, at all.

Senator MCFARLAND. I believe Mr. Bradley is our next witness.

STATEMENT OF W. H. BRADLEY, CHIEF GEOLOGIST, GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

Mr. BRADLEY. The testimony already presented before this committee, Senator, has shown pretty clearly that we are using up our mineral raw materials at progressively increasing rates, and furthermore that we are, on the average, discovering new reserves at a

diminishing rate. The Chairman of the committee has emphasized and made it very clear that it is highly desirable for this country to do everything it can to become as nearly self-sufficient as we can in all of these mineral raw materials, particularly the ones now regarded as strategically short. It seems to me that the role geologists should play in that goes back to what we might call "first principles;" that is, to discovery.

Geologists do not believe that we are a "have-not" nation. In fact, we in the Geological Survey took a rather hard, long look at the mineral situation when we were working jointly with the Bureau of Mines in preparing this report on and appraisal of the mineral resources of the country, in order to determine what our most effective course of action should be in the postwar period. We came to the conclusion that we not only are not a "have-not" nation but we are rather optimistic that there are more deposits to be found.

Ore deposits of any kind, whether petroleum, tin, fluorspar, or whatever, are geologic entities. They are what they are, and they came to be where they are by a series of purely geologic processes. They formed not all at the same depth but at various depths in the earth's crust. Those that are exposed are exposed largely as accidents of erosion. We believe there is good geological evidence to believe that there are as yet undiscovered deposits that do not outcrop or that only have obscure surface manifestations; and furthermore, that it is going to be difficult to find them; it is going to be less a matter of tramping over the hills as the old prospector did, and recognizing definite mineralization, but more a matter of recognizing various subtle differences in the rock alteration, or in working out the geology of large regions, their structural patterns, and then projecting below the surface to locate the most likely places to drill, thereby eliminating the less probable areas. Geologic reasoning will thus bring the attention to focus on the most probable places to explore further for new ore deposits. In other words, what is needed now is exploration and prospecting guided by geology, geochemistry, and geophysics.

We have devised a plan to map systematically the geology of very considerable parts of the United States, taking the most important parts first, that is, the most important because they appear to have the highest promise of yielding new discoveries. The plan that we mapped out calls for a gradually increasing rate of activity from a little over a million dollars a year in 1946 to $2,000,000 in the current year, and gradually on up to a maximum of about $5,000,000 a year in the year 1951, and then leveling off and maintaining that level of geologic exploration at a uniform rate for an indefinite number of years. We think we can operate more efficiently and more effectively at a stable rate, rather than a fluctuating or gradually increasing rate of activity.

We have at the present time probably less than 10 percent of the United States mapped geologically at a scale that is necessary to guide exploration for mineral resources. That ranks us down to about fourteenth or fifteenth among the nations of the world in knowledge, basic knowledge, of the geology of our country.

I think the intention of the Congress was that geologic effort and technologic effort should be increased in order to try to rectify this situation, to correct the downward trend of discoveries of mineral raw

materials, and to do everything we could to enable this country to come nearer to being self-sufficient in times of stress. Actually the House action this year has curtailed that activity by a very considerable amount. It has curtailed it not only in the obvious cut in the Geological Survey's appropriation item, but in another item that was hidden. There was transferred to the Geological Survey from the Bureau of Mines the function of mineral exploration and evaluation, an activity that was estimated to require about half a million dollars to operate—at least that. We were requested to absorb that activity, thereby still further reducing Geological Survey appropriation about a half a million below the $1,690,000 which the House allowed. I don't think it would be very good business to throw away the investment we have made already in our geologic projects in order to undertake this new function, essential though it is in the search for new deposits.

I think you might be interested in knowing that we are spending considerable effort not only on systematic geologic exploration but also on geophysics as an aid to that exploratory phase of the geology. We are also supplementing that with research on methods of geochemical prospecting. Geochemical prospecting is a new tool that has not yet been tried out. Our research has been going nearly a year, and is beginning to show some rather high promise. The theory is that every ore deposit when it came into being emitted what you might call exhalations of vapors or solutions that went out far beyond the actual zone of concentration of the ore minerals, and that those traces of elements so exhaled can be picked up by ground waters and moved into streams, there to be detected by very subtle chemical means; that they also went into and were concentrated to some extent in the soils. And we know, further, that certain plants growing on those soils will concentrate, some of them thousands of times the concentration of the metals that occur in the soil, so that we are finding that by measuring the amount of those metals in the stream water, in the soils, and in the plants that grow on them, we think we can determine means of tracing back to a likely place to explore for a hidden mineral deposit. Both geochemical prospecting and geophysical prospecting, then, are supplements to geologic exploration. All three, when combined, provide means of reducing the cost of physical exploration—that is, of drilling—because they eliminate a great deal of barren ground and thereby lead to concentrated effort on the most probable places.

That is the only statement I wish to make, unless you have some particular question you would like to ask.

Senator McFarland. I don't know that I have any particular questions. I think your work is very important work and should be carried on if we expect to go forward in this development work. I agree with you that the day of the prospector discovering minerals is over.

Mr. Bradley. It is going to be tough from now on.

Senator McFarland. And even when you get them discovered, the mining will be more expensive, so that makes your work important for both reasons.

You might expand a little bit on just what you are doing in this geochemical field, as to how much money is being spent and how much is needed.

Mr. Bradley. We are expending approximately $75,000 a year on that activity, during the past year or year and a half. I don't think that needs to be increased. It just needs to be maintained at about that level and not decreased.

We feel that we have a balanced program of research and systematic geological surveying and exploration, and that the cuts that were proposed, we feel should be administered across the board, which means that all the activities must take their proportionate reduction; otherwise it throws the program out of balance, and we have gone to a deal of trouble since the war in trying to establish a balanced program. It will cause a good deal of reshuffling of our efforts.

Senator Malone. In this geophysical work, Dr. Bradley, what importance do you attach to it as an additional factor in the discovery of minerals?

Mr. Bradley. We regard geophysics as a tool of geology, the application of physics to geology. Geophysics will determine irregularities or discontinuities in the earth's surface, but you have to know what those are, what they mean. In other words, you have to interpret them in terms of geology in order to proceed from there on intelligently. The problem of discovering new mineral deposits, as Senator McFarland has pointed out, is going to become tougher and tougher. Those that are found have only obscure surface manifestations. That means we have got to use every resource possible in determining what is hidden, what is underground; and geophysics is going to play an increasing role in that discovery process, simply because it will go underground. We are developing geophysical methods, new ones, and testing out ones like our air-borne magnetometer, which we have been working with since the middle of the war, to test as many different kinds of terrain and different kinds of ore deposits as we possibly can, or rather, to elucidate the geology associated with ore deposits. Some of these are being made in large regions in which we know there is mineralization in order to see how effectively we can use it to reveal subsurface structures that can be interpreted in terms of geology.

Senator Malone. Would you for the benefit of the record, if you have not already done so, briefly outline the principles upon which the geophysical work operates?

Mr. Bradley. It is a complex subject, Senator.

Senator Malone. I know it is a very complex subject, but just the broad principles.

Mr. Bradley. Dr. Lee is probably better able to do that than I am.

Senator Malone. We intend to hear Dr. Lee.

Mr. Bradley. Suppose then, if I may, I leave that question specifically to him?

Senator Malone. Very well. Do you have any further statement to make?

Mr. Bradley. No, sir.

Senator Malone. Thank you, Dr. Bradley. You will be available to the committee at any time?

Mr. Bradley. Yes, sir.

Senator Malone. We will now hear Dr. F. W. Lee. Dr. Lee, you may state your connection with the United States Geological Survey, and if you have a written statement you may file and make any comments you care to. What we are particularly interested in, Doctor, is

to determine—well, the questions asked Dr. Bradley. You might cover first, if you would, the broad principles, not in technical detail, of how this new method operates, what part it plays in the discovery of new minerals, and how important you think it is as an additional factor in the discovery of new minerals.

STATEMENT OF F. W. LEE, GEOPHYSICIST, GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

Mr. Lee. In the first place, Mr. Chairman, I would say that no part is bigger than the whole. In this I mean that geophysics combines three sciences—the science of geology, the science of mathematics, and the science of physics. It requires the limit of knowledge in each of those branches. There is no geologist that knows mathematics sufficiently well to take care of geophysics. There is no physicist that knows everything about geology, and no mathematician that knows geology and physics to the same degree. For that reason it is, you might say, a team operation, a team service.

From the historical point I will say that the Geophysical Division of the Bureau of Mines, which was established in the Bureau of Mines as part of the Bureau of Mines and has been very carefully supported by the Bureau of Mines, has set up an organization which meets the above particular needs of this science. In other words, we have carefully selected, or had carefully selected, inasmuch as this organization had been expanded by Secretary Krug since November 16—we have combined geologists who had their doctor's degree in geology, we have had people who had their doctor's degree in mathematics, and people who had doctor's degrees in physics and mathematics, and the work is team work. In other words, it was very difficult for everybody to cover all the branches in the work of that organization which was started in 1928 by the Bureau of Mines. We have felt our way very slowly, because it was a very slow, evolutionary process.

I have prepared a record for this committee which shows the work that has been done in gradually developing our mineral resources and becoming increasingly more and more effective. I will summarize the statement by saying that we have spent, up to November 16, 1946, a total sum of $723,000, and have established mineral deposits and other national assets to the extent of $469,891,000.

Senator Malone. You are talking about values?

Mr. Lee. About values established through geophysical work. In other words, we feel that we have given the Government, as a result our geophysical work, as much as any other governmental agency.

To this I will also add one more feature, that the Geophysical Division of the Bureau of Mines has been responsible solely—it is acknowledged by the Director of the Bureau of Mines, Dr. Sayers, as well as the Under Secretary, Mr. Chapman, that the acquisition of the international territorial waters around the United States, known as the Continental Shelf, was originally started in our organization and pushed through channels to a successful conclusion.

Senator Malone. You are talking now particularly about oil?

Mr. Lee. Talking about oil and minerals off the shore. Naturally, the exploration of this type of deposits can only be done by geophysics. It is not a mineral prospect in the normal geological meaning, where

you can take samples and make investigations. It is a purely geophysical problem.

Coming back, I will say this: Geophysics primarily has the evaluation of fields. By this I mean natural fields, magnetic fields, gravitational fields, seismic fields which are detected by means of sound through the ground. Then it also has the application of artificial electrical fields, which can be artificially administered and measured; and the reaction which the ground makes to these various fields, and what to measure, in order to get the required geological information, is primarily a geophysical problem. In other words, you have to know what, as well as how, to measure in order to get the most geological information. There is more to it than just pure gology. There is more to it than just pure physics. There is more to it than pure mathematics. It takes the combination of the three to make a successful investigation.

Senator MALONE. Right on that point, Doctor. In your reference to the use of electrical devices, are you referring to the speed of reaction of the electrical waves?

Mr. LEE. No; it is more complicated than that. If you apply, as an illustration, electrical current to the ground just in a very simple way by two electrodes, you normally say that the fields of the current—the way this field divides in the ground—depends upon whether one electrode is positive and the other electrode is negative. What actually happens in the ground, if you reverse the electrodes and put the same potential back, making one end positive and other end negative, you do not get the same current field through the ground. In other words, the positive current through the ground is an entirely different current field than the negative one. We have been using that very successfully, as an illustration, for the area around Leadville, where there are lead and zinc deposits. Here the field of the current area is related to the tightness or looseness of the rock formation. The tighter the rock formation, the less current distance will be observed, and anyone who wishes to make a very careful geological study of work by the experts on mineral recurrences, such as, I might say, the textbooks, which are normally available to everybody, will find that almost all of the ore occurrences are related to the tightness or looseness of the rock formation. If we can differentiate the tight ground from the loose ground, we cannot say that all the loose ground is mineralized, but we can say, "If it is mineralized, here is where you will find it." In other words, we will reduce the chances of finding ore to a very small area or to a very limited zone. In other words, we have in the past developed a new system of determining these factors of the ground which can be measured at depth.

Senator MALONE. Right there, Doctor, then, is where your geology will come in, after you have determined the looseness or the tightness of the ground.

Mr. LEE. We try to get every bit of information that the geologist has. If the geologist does not have the information, we ask him to kindly get it for us before we start to work. In other words, if we say as an illustration that the occurrence of iron ore in the area of Iron County, Utah, is really related to the Homestake line on the contact with the monzonite determined by the geological, can it be said that the Three Peaks area, too, has the same geological background

that the Iron Mountain deposit has, or that the Granite Mountain has? Is it on top or bottom of the Homestake line? Does the geological work indicate that this area could contain mineralization? We ask for the geologist. We won't try to go out there and make a survey or make an aerial survey unless the geological information warrants. It is a geological problem pure and simple.

On the other hand, when it comes to making a detailed study of this area, determining whether this portion of ground is mineralized or is not, we will take that responsibility by making geophysical measurements and determining in these areas definite places where these minerals may be found.

Senator MALONE. First the geologist really narows the field of your work, and then you narrow it to a still greater extent?

Mr. LEE. We narrow it one point, and we will lay out the drilling program as to what portions of that area drilling should be done in.

Senator MALONE. Diamond drilling?

Mr. LEE. Diamond drilling to prove or disprove that this is good or is not good. I mean it may be geophysically good but not always mineralized.

Senator MALONE. Then the diamond drilling is not gone into, is not undertaken by private industry?

Mr. LEE. We found in working with large corporations, the big lead companies and the American Smelting & Refining Co., that they were only too happy to give us any help they could. In other words, the drilling work we have had to do has been done with the greatest of ease by those organizations. They have said, "Please give us a drilling patch. We are happy it drill it out." They have worked with us 100 percent.

Senator MALONE. You feel that you have been largely instrumental in discovering new bodies of ore or additional bodies of ore?

Mr. LEE. Additional bodies of ore. Our great handicap in the West has been that there are too few people who are able to do this work, and we have said that in order to get more information on minerals, to give more help to prospectors, more help to the companies, it was necessary to start at the fundamental basis and begin with the mining colleges and schools and give them an opportunity to learn. They themselves are too poor in their appropriations—and I know them all very well—they cannot afford to buy geophysical instruments. I have hoped that we could set up in the Bureau of Mines an organization which would furnish the necessary equipment and instrumentation which those schools could use, and also work with them to the extent that we could gradually introduce them to modern methods of prospecting, then gradually turn over the whole thing to the State and just act as a guiding agency to see that nothing happens and nothing goes wrong, so that the results work out properly. I don't think the Federal organization can handle the entire United States the way it is organized at the present time, because it requires that entirely too much ground, too much investigation must be done, too much work for a small staff. In other words, we have to amplify ourselves, put ourselves in the capacity of an electrical amplifier by which we can modulate the strength of these colleges and organizations, and develop our minerals through them.

Senator MALONE. You feel we should encourage these geological departments of the various schools of mines so that if they were furnished proper equipment and a little supervision, they would then develop the ore resources?

Mr. LEE. That is absolutely the only chance, because our organization is entirely too small. We had only 50 men during the war. We cut those 50 men down to 25 immediately after the war to cut down expenses. Now the organization has been disbanded. It has been reassembled to some extent in the geological survey, but the old functioning of the organization is now a thing of the past.

Senator MALONE. Is there any of this necessary equipment purchased during the war for any organization, that might be available to colleges now, in the way that other highly technical equipment has been made available to them?

Mr. LEE. Well, we have a small amount, I would not say very much, equipment which could be made available.

Senator MALONE. Is this equipment made especially for this work, and is there other electrical equipment that could be assembled for it, that might be available?

Mr. LEE. We find there are two kinds. Some of it we can buy. Anything that we can buy, we buy. We do not try to make anything we can buy. On the other hand, there are many instruments that you cannot buy, which we have to make ourselves, and the Bureau of Mines has been very courteous and very helpful to us. They have given us sufficient machine tools, sufficient equipment, and all of the facilities needed. We have not been extravagant. We have only taken one little floor in a building which the Government had already acquired prior to the war for expanding the customs of Baltimore, a more or less factory storage building, and we have just one floor of that factory storage building to house everything we had. In other words, we cut everything to the core.

Senator MALONE. You still have that space?

Mr. LEE. We still have that, but it is going to be curtailed this year, because they have greatly increased the cost. Although it is a Government building, owned by the Government, the cost that they have been putting on it for custodial purposes has been exorbitant. Now, I mean this: When the Navy operated that building the cost was about $8,000 a year to operate the whole building. At the present time the PBA has increased the cost of that building to $44,000.

Senator MALONE. What is the PBA?

Mr. LEE. That is the organization that takes care of all the housing of governmental activities. They have piled it on us. We had done considerable work for the Navy on magnetic surveys for submarines and things of that kind. We did a lot of work for them prior to the war and a lot of work during the war. The Navy was very liberal and helpful. The Navy charged us for the services of that building $800 for 6 years. I mean for the whole time that we were there, they charged us $800 for the 4 years. Now, these other people want to charge us $8,000 for 1 year—absolutely, unquestionably rotten. I mean that, too. That is the proper designation.

Senator MALONE. Doctor, I agree with you in your statement that it is an important factor. I have been in touch with your people in Nevada, and while I do not attempt to go into technical details—that

is for you folks who spend all your time on it—I agree with you it is an important factor.

Now then, for the benefit of the committee, would you mind just taking the time to name the important factors, that you consider important in the discovery of new minerals; that is to say, minerals that are mostly underground where the outcrop is not sufficient to indicate the presence of such metal? What are the activities beginning with the United States Geological Survey and their mapping which should be pursued by the Bureau of Mines and the United States Geological Survey?

Mr. Lee. I am just going to take one illustration to bring out all the factors. We were asked to make an examination of the tin possibilities in Coosa County, Ala.

Senator Malone. I have heard of that project.

Mr. Lee. The geologists gave us information saying that there was no tin in Coosa County, Ala. They made a study of the pegmatite dikes which are tin bearing in that area. The outcrops of those dikes have been carefully examined by the geologists, and they said that they contain no tin.

Senator Malone. There is no indication of tin on the surface?

Mr. Lee. There is no evidence of tin there. Well, in the first place, we asked the geologists, "How did you differentiate those dikes?" Well, they didn't give me much information, much help on that. I went down there and examined the area and I found that there is a considerable amount of tin floating in that area, which must have had its origin from some tin-bearing dike somewhere, so we said: "Well, let us see what the geological situation is." We questioned the operators and we found that they did not give us the full geological information.

There were three types of pegmatite dikes in that particular area, one of them the primary quartz, which was very resistant to erosion, and it stuck out all over the country and did not contain any tin. Some of them contained mostly feldspar and were very soft. They had been eroded away and covered by what we call just ordinary weathered rock. Then there were some other formations which were subjected to—a very technical geological term—metamorphosis related to grizanization, containing in some cases tin, in some cases some portions well converted to mica. In those cases where there were tin-bearing dikes we would map all the buried dikes in that area and measure the whole dike pattern in the ground, even where no outcrops occurred at all.

We used electrical methods to differentiate those dike positions, and we then checked them by trenching on them and digging down on them to prove that they were there. We did find tin in some of those dikes. Some were barren—did not contain tin. On the other hand the geologists were 100 percent correct in saying that there was no tin in those dikes which outcrop, but only the geophysicists gave them a complete dike pattern and said: "You have only half analyzed the area. You don't know what you have in there until you have examined a large number of other dikes in there which do not outcrop. Then you can say whether you have tin or not." The war stopped that work.

Senator Malone. Right on that point, was any digging or prospecting done?

Mr. Lee. There was a small operation there in connection with those dikes, and in some they found tin and in some they did not find any tin. In other words, it was what I considered only a very superficial exploration.

Senator Malone. What percentage did it run where they did find tin?

Mr. Lee. About 2 percent.

Senator Malone. What is considered commercial tin ore?

Mr. Lee. About 2 percent.

Senator Malone. That is considered commercial?

Mr. Lee. Yes, sir; 2 percent is considered commercial. People are very happy to get 2-percent tin. But that was not enough. I mean the work in the district was entirely insufficient for this area. The project was stopped because the war was over. We had access to tin from the outside, and tin exploration was clamped down by the War Production Board very quickly.

Senator Malone. Do you think there should be further exploration?

Mr. Lee. Yes, sir.

Senator Malone. That is a good illustration, Doctor, but to get back to the matter we were discussing, I understand that geological work would come first, including mapping and studying the general character of the country; then your work would follow, and then the Bureau of Mines?

Mr. Lee. Drilling and checking to determine the quality and quantity of the ore.

Senator Malone. What, in your judgment, would the work cost to continue at, perhaps not the war rate, but to continue the work in a way that would be effective and keep your organization operating? What would it cost?

Mr. Lee. The annual cost with the reduced force that we have at the present time, cutting down to half what we had during the war, would cost about $175,000 a year.

Senator Malone. Do you have enough equipment to operate with?

Mr. Lee. Using the present equipment that we have at the moment. The program would not include the plan of expanding the activity and giving the State institutions advantages in teaching the future miners how to prospect—in other words, the broadened program. It is just a narrow program that is being carried on at the moment.

Senator Malone. I understand that, Dr. Lee. It might not be the opportune time to try to expand it, but also I am of the opinion that if proper information is made available to the committee, most Members of the Senate want all the factors that they consider important, made available to some extent.

Mr. Lee. I want to mention one more modification of that statement, that this mineral investigation is mineral exploration which does not include the aerial magnetometer work, because we at the Baltimore laboratory have not been developing that activity as part of our original set-up. The total estimate for all geophysical work planned for fiscal 1948 was $419,000.

Senator Malone. Do you consider that part of it important?

Mr. Lee. It bears the same relation to geological aerial mappings at the present method of, you might say, over-all mass geological work would imply. In other words, it gives us a tremendously large

amount of important information over a very large area in a very short time, which makes possible more detailed geological work in those areas which are important.

Senator MALONE. And reduces the expense?

Mr. LEE. It reduces the expense.

Senator MALONE. Dr. Lee, we are very glad to have your testimony, and thank you for your appearance.

Mr. LEE. If you care to have this paper I will leave it for the record. It will give the past experiences for the last 20 years.

Senator MALONE. The committee would like to have your statement for the record.

(The paper entitled "Economic Evaluation of Geophysical Work" follows:)

ECONOMIC EVALUATION OF GEOPHYSICAL WORK

(By F. W. Lee)

Probably there is no better time than the present for making an inventory concerning the costs of public projects and the values received for moneys expended, particularly at this time when additional planning and action will be needed for meeting full employment emergencies following the war activities.

Into this general plan fall scientific activities which have national application in providing proper outlets for new industrial activities, as well as for extending old ones. That geophysics will be capable of providing, assisting in, and executing such plans will be seen from the economic evaluation of the past record of the Geophysical Division of the Bureau of Mines.

A résumé has been prepared beginning with the founding of this activity and extending to date.

Economic evaluation of geophysical work concerns itself primarily with the establishment of the values which such work has produced. In some instances the recognition of values so established is very simple, as for example in the discovery of a new ore body which can be evaluated by knowing the grade and tonnage. It will be seen that geophysical work has been very effective in locating such new ore bodies in territories which had been previously considered barren, or had been abandoned. Geophysical activities of this nature may be considered to establish values in a positive sense. Geophysical work may be considered also to establish values in a negative sense, as, for instance, through the reduction of drilling costs. Mineralized areas on which drilling operations had been planned may be proven barren by geophysical exploratory methods, thereby permitting money allocated to such projects to be saved.

Projects related to social wealth and general public welfare are difficult to evaluate in terms of dollars and cents. Into this category fall the discovery of additional water resources for communities, cities, and military reservations; the evaluation of large regional areas in relation to possible oil accumulations therein, etc.

Engineering projects, too, are difficult to evaluate, as, for example, surveys of dam sites. Here, for instance, one location may require more concrete than another because of less favorable bedrock elevations. While geophysical surveys give the most economical location, the saving due to geophysics must be compared to a hypothetical location which would have been used had no geophysical work been done. Or comparison must be made with drilling expenses which would be required if a geophysical examination had not been made. A drilling program to take the place of a geophysical examination would often be excessively expensive and make such exploratory drilling costs prohibitive.

Geophysical activities require that a large portion of time be assigned to research. The Government has realized the ultimate value of scientific researches and has often subsidized them since, as in the case of the atomic bomb, they have established values of great importance to the Nation. Such values do not permit immediate discounting. They are nevertheless of a fundamental character and necessary for progress. Research projects are what may be called intermediate stepping stones of no immediate economic worth which lead to an ultimate goal which has generally an exceedingly great economic value. Geophysical exploration techniques inherently require many such stepping stones from many branches of science, which must be carefully integrated into a composite whole before such a

goal can be achieved. They comprise fundamental researches in mathematics, instrumentation, and field techniques. Such researches are exceedingly slow and difficult to execute and frequently require several years before a real showing is possible. For this reason the setting aside of funds on a yearly basis founded on values established in short intervals does not permit the completion of the researches needed for the ultimate objective. While Congress has realized this condition in certain governmental branches such as the Bureau of Standards, it does not apply the same psychology to other governmental research organizations. The Bureau of Standards has sold itself to Congress as a research unit. The Bureau of Mines so far has not emphasized research to the same degree, although it can and has established research values of the same order as those of the Bureau of Standards. Intrinsically it rests upon a much broader foundation since it encompasses all of the mineral industries, and has research problems related to the discovery, mining, and utilization of the Nation's mineral resources and the products derived therefrom.

Geophysical activities, as annotated below, have been so far confined to the United States and its Territories. However, it is becoming increasingly apparent that requests for such aid from sister republics will warrant the extension to them of much help for our own as well as their best interests.

1928

Geophysical work was first started by the Bureau of Mines. At this time much was being promised to the mine and other operators on a more or less promotional basis by commercial geophysicists. The Geophysical Division endeavored in this period to separate true scientific information as to geophysical methods from optimistic or promotional chaff, thereby providing a gage, so to speak, for the mining, engineering, petroleum, and geological professions.

During this period the Mineville area of New York was magnetically surveyed as were certain portions of Cornwall, Pa. The results clearly showed that even with the best instruments and techniques, it was not possible to determine singularly the location of iron magnetite deposits in the Mineville area. On the other hand, it was relatively easy to locate the iron deposits at Cornwall, Pa.

Resistivity, self-potential, and magnetic work were also applied to mineralized zones in the Sudbury area of Canada. The results of this work clearly indicated the importance of applying different geophysical methods to the same area.

All of this work was strictly of a research character, and no economic value of a direct nature could be assigned to it, although it unquestionably saved many thousands of dollars to industry.

1929

This year was a continuation of the same plan started in the previous year, but concentrating primarily upon electrical induction methods of prospecting. The electrical ground penetration of radio waves was tested at Mammoth Cave in Kentucky. Induction methods were also applied to nickel deposits in the Sudbury area. (No estimate.)

Quantitative methods were developed in the application of magnetic prospecting to ore deposits having the form of dikes. These methods are still in use. (Value very large but cannot be estimated.)

Resistivity studies were made on geologic bodies having very high resistivity values such as the rock asphalt deposits of Kentucky. The results of these studies led to the first electrical exploratory work on oil deposits, in Allen County, near Scottsville, Ky. Researches at this location led to the first discovery of an oil deposit by purely electrical methods. The oil field was a small one, very local in character. (Estimated value, $10,000.)

1930

Work on oil exploration was continued at White Chapel, Ky., not far from Bowling Green. Favorable areas were indicated for oil occurrence, and oil now is in production from this area. (Estimated value, $50,000.)

Research on the determination of boundaries around the Le Grande oil pool which had just been discovered showed that such boundaries can be predetermined, thereby avoiding useless drilling. (Estimated minimum value to pool operators, $15,000.)

Researches upon the application of electrical resistivity methods applied to the Cornwall iron area of Pennsylvania showed very definitely that geological discontinuities could be determined by electrical methods. (Not estimable.)

Magnetic surveys made at Iron River and Michigana River, following much fruitless and expensive drilling by the United States Steel Co., clearly demonstrated that it was possible to establish the continuity of an ore body cut off by a cross fault. Measurements were checked by development and the ore was mined. (Estimated value, $1,000,000.)

1931

Work on the United States helium reservation, which had for its objective the delineation of the general structural boundary of this deposit, and information concerning possible loss of gas from any offset wells on adjacent properties, was undertaken. Results of this magnetic survey clearly marked the structural boundaries and also showed that the United States Government leased properties completely surrounding the structure with no possibility of offset wells draining the gas. (Estimated value, $200,000.)

Researches were conducted upon electrical skin effects or the flow of electricity at or near the surface without adequate depth penetration in mineral prospecting. This work was done in cooperation with the Dow Chemical Co. The results of this work led to the abandonment of alternating currents for any except very shallow resistivity measurements. Ultimate value not estimable. (Immediate value of research estimated, $10,000.)

1932

Additional work was done on the helium reservation for spotting favorable locations of additional wells. It was found that the structural contours of the Alibates formation reflected topographic highs and lows in the crystalline basement but was offset from them. Favorable structures for drill locations could be determined from the magnetic maps. (Estimated minimum value, $25,000.)

A research project on chrome deposits was started, but owing to the complex geological conditions the results were negative.

1933

A geophysical survey of the mineral possibilities of Puerto Rico was undertaken. Magnetite deposits of the order of 600,000 tons were indicated. Over 2,000,000 tons of glass sands were measured. Marble deposits, very similar to Italian and French marbles, were outlined in an area 1 by 3 miles. (Estimated value, $5,000,000.)

Measurements to bed rock for dam-site locations were made at the Grand Coulee Dam. Geologically there was a buried faulted condition at a proposed bridge-head location for spanning the river. Geophysical methods located this dangerous situation and the location of the bridge head was changed. Without considering the value of the bed-rock information, the loss of such a bridge would be very great. (Estimated value, $1,000,000.)

Further studies of bed-rock conditions of the dam site disclosed no dangerous conditions. (Estimated value, $1,000,000.)

Research work was started for measuring the damage done to buildings by blasts in quarries.

1934

Research work on quarry-blast studies were continued. Mechanical vibration from earthquakes prior to this time was based on a purely qualitative foundation. It was necessary to invent equipment for producing mechanical vibrations of a definite character as well as inventing an instrument for precisely measuring ground vibrations.

A water survey was started in Nevada for releasing drought conditions. White Pine County received a large amount of help as well as many other locations. (Estimated value, $100,000.)

The flood-control project on Muskingham Dam sites required the geophysical examination of 12 sites for the Army engineers. Geophysical surveys saved much diamond drilling. (Estimated value, $120,000.)

Vibration work on rock blasts was carried out with research equipment for field work. Results showed that generally the vibrations were not large enough to cause damage to buildings. The work stopped many nuisance suits to quarry operators. Value is difficult to estimate since one quarry alone paid $45,000 for such damage suits. (Estimated value, $100,000.)

1935

A water survey was made for increasing the water supply of El Paso, Tex. Geophysical work showed there was a bend in the gravel composing the buried

run-off in the bolson between the Waco and Franklin Mountains, indicating a very substantial gravel deposit at other locations in the bolson. Drilling was recommended at this location and a large amount of water reserve was established. Prior to this survey a water well became salty, causing great anxiety. (Estimated value, $1,000,000.)

A large amount of water work was done in Nevada at Carson flats and other locations of a research and experimental nature for the purpose of locating artesian aquifers. These researches are very promising, but so far have not been tested by drilling.

1936

The Hawthorne water at the naval reservations was investigated for additional sources of water. A fault was delineated which controlled the subterranean run-off into Walker Lakes. (Estimated value, $5,000.)

A general ground-water survey of the Hawaiian Islands was started for establishing additional underground water resources for the islands.

Magnetic surveys of the Comstock area of Nevada was begun for locating possible contacts favorable to gold occurrences. No large deposits were found. However, several small ones proved productive. (Estimated value, $25,000.)

Research work was started on chrome deposits at Soldiers Delight, Md.

Ice and snow surveys were made at Soda Springs, Nev. All of a research nature in character.

Research work was started on the shoestring oil fields of eastern Kansas Several small fields were found. (Estimated value, $25,000.)

1937

Ground-water surveys in Hawaii were continued. A magnetic and resistivity survey was made on the Florida ship-canal project, with reference to possible draining adjacent ground and thereby cutting off of ground water from the southern portion of the peninsula. (Estimated value, $75,000.)

Chrome searches were started in Oregon and California. Researches were continued on oil in eastern Kansas. Oil prospecting was also started in the Ashley, Lansing, and Rose City areas of Michigan. The project was of a research character. The results have been of far-reaching importance for charting stratigraphy and elevations of important ground formations using electrical methods.

1938

Ground-water surveys in Hawaii were finished. As a result the location of buried floating islands of fresh water on salt water were discovered as well as the thickness of the fresh water. Also perched water tables at the Schofield Barracks for the Army were discovered. (Estimated value, $2,000,000.)

Work was continued on chrome in California on Grey Eagle deposits. (Estimated value, $750,000.)

Researches were started in the Kentucky fluorspar areas of Crittenden and Livingston Counties. It was found that geophysical methods could determine the fault patterns and thereby indicate favorable possible mineral locations.

A very comprehensive chrome survey was made in the Casper Mountain area indicating chrome deposits of the order of 500,000 tons. (Estimated value, $50,000.)

1939

A magnetic survey was made of the Florida peninsula with a view of determining the topography of the crystalline basement. As a direct result areas favorable for oil prospecting were established and subsequently leased by oil companies. Values established, estimated for leasing purposes only, $10,000,000.

Work was started on a geophysical survey for a tunnel site at Cripple Creek for dewatering mines.

A geophysical survey was made on buried channels under the glacial till in the Chelmsford area of Massachusetts. There is an urgent need concerning the location of such channels as sources of water supplies for cities and communities. (Estimated value, $50,000.)

Researches were made in field technique for determining buried valley channels for their gold content. Also for determining, if possible, the location of old feeders to laccolithic structures.

1940

Magnetic surveys of northern Florida were continued and extended into Georgia. So far no publication has been issued on it. Work was begun on the

drainage tunnel site at Leadville, Colo. Work on gold channels were continued at Newton Flats, Calif., where a channel 200 feet below the ground surface was delineated and found gold bearing. (Estimated value, $10,000.)

The city water supply of Rochester needed additional sources of water. A buried preglacial channel carrying water was found by geophysical means. (Estimated value, $50,000.)

The water supply of the city of Fargo, N. Dak., needed additional sources of water, and a field survey was made for buried gravel channels. No gravel channels were found but much speculative gravel areas were eliminated. (Estimated value, $5,000.)

1941

Mineral surveys for mercury deposits were made at Johnson Creek, Oreg. A mill worth $100,000 was to be abandoned for lack of ore. Additional cinnebar ore was found to operate the mill. (Estimated value, $500,000.)

Taylor Ranch, also mercury prospect, found ore location. (Estimated value, $45,000.)

Additional mercury deposits were found at Maury Mountain, but no record of drilling was received.

Oil researches were started in the Titusville area of Pennsylvania to determine, if possible, means for discovery of stratigraphic trap deposits similar to the Music Mountain deposit.

A geophysical survey was made on Governor's Island in the Boston Harbor for determining the elevation contour of the rock core of the drumlin island. The island was planned as an extension of the main Boston airplane field and comprised about 60 acres. Estimated value on money saved on contract specifications. (Estimated value, $40,000.)

The Leadville, Colo., project was finished planning a 6-mile dewatering tunnel. (Estimated value, $50,000.)

A search was made at Oxford, Pa., for chrome, but no large deposit was found.

1942

Oil researches near Titusville, Pa., were continued and the results are very promising for finding oil deposits in this area, as well as for measuring the direction of sand extension in wells. Owing to the research nature of this project no value can be set except that its economic results may prove very valuable.

Large deposits of black sands carrying chrome were delineated in Oregon comprising about 750,000 tons, worth about $6 per ton. (Estimated value, $4,500,000.)

A magnetic and resistivity geophysical survey disclosed a large iron deposit at Bourbon, Mo. Estimated tonnage over 100,000,000 tons. (Estimated value, $400,000,000.)

A geophysical test was also made on the Malden acre of Missouri on a deeply buried dome which is now being drilled.

Money saved on locating tin bearing pegmatite dikes in Coosa County, Ala. (Estimated value, $40,000.)

Geophysical survey on mica deposits in Alabama proved values of $35,000.

The Cordero area in Nevada was prospected for cinnabar. (Estimated value, $5,000.)

Geophysical work was executed at Red Lodge, Mont., for chrome, settling a speculative geological problem.

1943

A magnetic survey was made at Boyerstown, Pa., as a basis for recommending a $2,000,000 RFC loan. Insufficient ore was found and no loan was warranted. (Estimated value, $2,000,000.)

The sum of $15,000 was set aside for drilling at Mahopac, N. Y., for iron. Geophysical work indicated no iron at this location and drilling not warranted. (Estimated value, $14,000.)

Geophysical surveys at Fort Ann indicated ore continuity and saved drilling. (Estimated value, $10,000.)

The Stoker-Marker iron deposit in Pershing County, Nev., indicated 182,000 tons of ore. (Estimated value, $700,000.)

The Cheever and Carr iron areas of Massachusetts were difficult to plan for d. d. h. locations and geophysical surveys saved random drilling. (Estimated value, $5,000.)

A project of prospecting for copper at Virgilina disclosed copper deposits of the same character as now worked but in new areas.

1944

Seismic surveys in Virgin Valley, Las Vegas, Nev., indicated about 6,000,000 tons of halite worth about $4 per ton. (Estimated value, $24,000,000.)

Magnetic survey at Moosehead Pond, N. Y. disclosed no ore.

Magnetic surveys at Mineville, N. Y., disclosed no ore.

Magnetic surveys at Dannemora, Russia Station, N. Y., disclosed small iron deposits of 100,000 tons. (Estimated value, $400,000.)

Geophysical surveys at Mountain City, Nev., indicated additional copper deposits. (Estimated value, $1,500,000.)

A small war project was carried out at the Hagerstown airfield for selecting a proper site free of magnetic disturbances for adjusting the magnetic compasses on airplanes. (Estimated value, $1,000.)

A very comprehensive naval research program was undertaken for submarine defense. The Navy contributed $20,000 for the project and the results were excellent. (Estimated value, $40,000.)

A large number of areas were examined geographically for possible iron deposits. Results showed that there were no iron deposits at these locations which saved drilling costs of over $10,000 at each location which would have been needed for securing this information. These areas were: Hardwood Island, Hammondville, Moosehead Pond, Buck Hill, Ore Hill Mine, Anstett and Tuttle Farm, Broughton-Ring, Iron Mine Hill, Sterling Lake area, and Pittsfield. (Estimated value $10,000.)

1945

Large new iron deposits were discovered in areas turned down by the United States Geological Survey in Iron County, Utah. Estimated tonnages of the order of 50,000,000. (Estimated value, $200,000,000.)

Iron tonnages of the order of 2,000,000 were indicated in the Cranberry area of North Carolina and Tennessee. (Estimated value, $8,000,000.)

The Brandy Brook flow area of New York indicated a probable tonnage of magnetite of from 1,000,000 to 2,000,000 tons. (Estimated value, $4,000,000.)

Geophysical abstract services. About 1,500 abstracts were prepared each year on geophysical work. The usual charges are $10 per abstract. For 16 years this would be worth while for an individual or company. (Estimated value, $240,000.)

Against this establishing of values there now is also a working pilot plant for making these researches and investigations having instruments and machinery valued at about $75,000.

While no fixed amount has been assigned to a geophysical budget, the money allocated to geophysics by the Geological Survey and the Bureau of Mines has been as follows:

Year	Cost	Established values [1]	Year	Cost	Established values [1]
1928	$12,000		1940	$50,000	$65,000
1929	12,000	$10,000	1941	50,000	636,000
1930	13,000	1,065,000	1942	50,000	404,580,000
1931	14,000	210,000	1943	50,000	2,729,000
1932	14,000	25,000	1944	100,000	26,041,000
1933	14,000	7,000,000	1945	200,000	12,240,000
1934	17,000	320,000			
1935	38,000	1,000,000	Total	798,000	459,891,000
1936	38,000	55,000	Inventories	75,000	
1937	38,000	75,000			
1938	38,000	2,800,000	Balanee	723,000	
1939	50,000	1,050,000			

[1] Not estimable.

This represents a total allocation of funds of $798,000 in 18 years, 1928–45.

From the above analysis it is seen that geophysical work has proven effective. There are indications that this activity will transcend the past performances many times. Specifically, in the acquisition by the United States Government of the Continental Shelves bordering the Coastal States and Alaska, the Geophysical Division of the United States Bureau of Mines initiated this program and assisted in guiding it through channels to its final realization in President Truman's proclamation 2667 dated October 1, 1945.

This, our greatest effort, represents an increase of potentially productive territory bordering the United States of about 750,000 square miles, equivalent to about five States the size of California. The possible oil deposits in this area may be of the order of 50,000,000,000 barrels.

The acquisition of this former international territory has been accomplished without the payment of funds, without any loss of life from conquest and with the consent of all the nations involved.

ACKNOWLEDGMENTS

The Geophysical Division of the Bureau of Mines wishes to acknowledge with thanks the help and interest which it had received from the Members of Congress, both in the Senate and in the House. Very little could have been accomplished without their frequent direct aid and quick action.

This work has had the support of the many operating associations, engineering and scientific societies, and universities. Their willingness to contribute means as well as personnel have proved of great help in carrying out the many projects.

Last, but not least, the unremitting effort of the State governors through their State mining engineers and State geologists have proved invaluable by making available detailed information often possessed by themselves alone and also giving the advantages of their long field experiences in their respective States.

This organization operated as part of the Departments of Commerce and the Interior under the executive administrations of Presidents Coolidge, Hoover, Roosevelt, and Truman. It should be mentioned at this time that the last three Presidents had often taken a direct interest in this work.

The tremendous support given this organization by its immediate superiors, Mr. C. E. Julihn, Dr. R. S. Dean, and Dr. R. R. Sayers, in the Bureau of Mines cannot be overestimated. Their encouragement in fostering the cooperation and contacts with the various branches of the Government have shown their broadmindedness They have clearly demonstrated how under a kindly guiding hand democratically administered governmental agencies can best serve the Nation.

NOVEMBER 15, 1946.

Mr. LEE. May I make one more suggestion at this time. I have had rather fortunate experience in the past in having had very close contact with a large number of Senators and Congressmen, and we worked very intimately with them on problems of their constituents and plans. Our relations were family-like, very cordial, and very harmonious. I have found that because of this condition we have been able to make most of our headway, and I attribute our success in our organization primarily to the help that we received both from the Senate and from the House. I mean that in considering the results that we have given you in our record over past years, I think the relations between the Senate and the House and the technical members of the profession throughout the country are the controlling factor, and the ability of access, the ability to discuss things, the ability to put problems up and say: "This is a technical situation; this is the social situation; this is the financial situation; this is the international situation," should be taken advantage of and will permit the organization to work in very close cooperation.

Senator MALONE. I think, Dr. Lee, that whoever the mouthpiece may be among members of the Bureau—probably more than one—they say mostly that you are the designated head of that information and have access, of course, to all of the details which they are not familiar with themselves, and for the benefit of the record I want to say we appreciate your testimony in that connection and we thank you very much.

Dr. Boyd, do you have any further statement you would like to make in connection with the handling or the management of the methods of locating mining claims?

ADDITIONAL STATEMENT OF JAMES BOYD

Mr. Boyd. Mr. Chairman, you have asked several questions in the last two or three sessions of this committee which gave me some thought, and I took the time to investigate the situation in the Interior Department regarding the statements in the annual report on the proposition of leasing mineral lands. I want to just clarify for this committee's benefit the situation as it now exists. I have talked to the Secretary about it.

There is no proposed legislation for this before the Congress for the leasing of mineral lands other than that for utilizing acquired lands. The Secretary himself has no firm position on the matter. I have not had an opportunity to think about and discuss it for recommendation to the Congress.

Senator Malone. Dr. Boyd, did the Secretary recommend such a system in his report to the President?

Mr. Boyd. The report to the President included some statements showing the arguments on both sides of the question, and suggesting that the Congress should consider the matter.

Senator Malone. In other words, his thought was that it should be changed from what it now is?

Mr. Boyd. It certainly is open for consideration.

Senator Malone. That is, changing from the plan of location by any prospector, or anyone at all, on a ledge that he may discover, where he can hold such a claim, 1,500 feet by 600 feet, doing his annual development work, and where he can patent it and it becomes his own ground—the Secretary thinks that should be investigated and some change made?

Mr. Boyd. It was with the thought that it might be possible to make some change.

Senator Malone. What was his suggestion?

Mr. Boyd. I think these expert witnesses that you have heard in the last few days have indicated that there is a very marked change coming about in the prospecting for minerals. The problems involved are different from what they were when the original mineral-land-management plan was evolved, and there are certain conditions or considerations on both sides of the question which ought to be considered by Congress.

Senator Malone. As I understand the testimony so far, most of the new methods are just additional techniques to discover minerals, either on ground that already been located, as Dr. Lee has stated, in working with the owners of such mineral-bearing ground, or working in open country where it is not located at all by anyone. Now, in what manner do these methods influence the change?

Mr. Boyd. As you know, in order to locate a mining claim and have a patent you must show mineralization on the claim. When you begin to work in geophysical methods you are working below the surface and you have the question then of working over wide areas, and private enterprise that will be searching for mineral deposits will need wider areas to work in than they have in the past.

Senator Malone. Now, to correct that, would you have to change the wording of the location notice so that it is not necessary to show a ledge in order to start work, or require the work? Or would you

think that is reason enough to change the entire system into a leasing system?

Mr. BOYD. Well, frankly, sir in the last few days I just haven't had a chance to come to any personal conclusion on it at all. I think some of these various points of view are worth putting into the record for the benefit of the committee, for the committee to consider.

Senator MALONE. What is the Secretary's point of view in that connection?

Mr. BOYD. He does not feel that he knows enough about it yet to come to any conclusion. He feels that a change should be made. He feels that there is sufficient evidence of it that we should consider the possibility of making a change.

Senator MALONE. The reason I questioned some of the witnesses very closely in that regard—I guess I mentioned it to you before another committee—is that Secretary Ickes made a very pertinent point in changing over from the location method to a leasing system. He did not bring us any reason such as you have mentioned now where a liberalization of the wording of the location notice might be ample, but simply said that a leasing system should be adopted. That appears not only, I think, in his report but certainly in some of his statements many times. So then, when Secretary Krug comes along, apparently following his footsteps, we naturally concluded that he believed in that method.

Mr. BOYD. Yes, I think that is the situation as it was. That position had been taken.

Senator MALONE. There is no question about Secretary Ickes' position in the matter.

Mr. BOYD. No, I don't think there was.

Mr. LEE. Mr. Chairman, may I make a remark on that?

Senator MALONE. Yes, Dr. Lee.

Mr. LEE. Mr. Broadgate—I don't know whether you are familiar with his activities or not, Senator—had proposed and worked out and carried through a new method of establishing mining claims based on geophysical surveys by individuals who could stake them very much in the same way they have done in the past, but not necessarily on outcrops, but allows them 1 year to drill, to prove that they are mineral in character. That was carefully worked out, and there was a lot of time spent—our organization spent a tremendous amount of time studying and setting that bill up, which I think has been pocketed at the present time, but it did not abrogate the mineral leasing system. It gave the prospector the same advantage he has had in the past, with the additional advantage of geophysical work, and many of the people interested said that that was something that they were looking forward to.

Senator MALONE. Dr. Lee, I would consider that what you might call liberalizing the law was pertinent at this time, due to these new methods or new factors that have entered into the location of mineral below ground. As a matter of fact, in the actual operation of locating mining claims, I have lived in the area all my life—no one ever questioned the prospector when he said he had found mineral, because if there was one rock sticking out of the ground he would think that that would lead to something, and that, of course, is what made a man stay

out there with a sack of beans for 6 or 8 months or half of his life, until he finally located something of value. That incentive is the thing we want to maintain, and if you could liberalize the laws so he did not have to sort of misrepresent it, so to speak, it probably would be helpful, but to say that because of this new factor—which I agree is a very important factor and should be taken into account, should be supported—to say that we must change the system so that he cannot own what he discovers but that he will continue to work on it, is certainly subject to considerable inspection of the thought and where it originates.

Mr. LEE. They had planned in their bill that the prospector should make a geophysical survey of the claim or the area with which he was concerned, and submit that report of geophysical work to the General Land Office, and the General Land Office would act on it and say whether it was correct or sufficient, and that would give him 1 year to do his drilling or prove that he had something, or he could keep claiming it.

Senator MALONE. Dr. Lee, it is probable that the prospectors, that really in the long run discover most of the minerals, would not be able to pay for a geophysical examination. As you say, as you so ably outlined, that is just one more factor. You might say that an area might be mineralized but you could not say that it is; therefore, it is just another factor that should be available for use to him, and I am still firmly of the opinion that no better system has been worked out—I will say that with the information presently at my disposal there has been no better method devised than to let a man that is broke every other way except he might own a pick and shovel, go out and keep everybody off of his claim as long as he works at it. There is no better method of locating mineral, is there?

Mr. LEE. I fully agree with you. I would not have that spoiled for anything in the world. I do not want to give the impression that I have any objection to the present system. The present system is wonderful. Keep it up, but also give the people who wish to say: "I would like to do a geophysical examination out here, and I would like to have some way of handling it legally."

Senator MALONE. No doubt it could be improved and liberalized, and I think any suggestion made should be given the fullest consideration, but it does irritate me, and it irritates a lot of people in the mining country to have someone who is probably entirely unfamiliar with the mining business, as the Secretary of the Interior usually is, continually throw in an element of uncertainty over whether they are liable to be almost immediately cut off and have to pay tribute to the Government to get out on the Federal lands and prospect. It just doesn't set so well, and it ought to be approached very carefully. And in my humble opinion if such a recommendation should be made to the President of the United States or the executive department or to Congress, and not broadcast just to upset the people that are in the mining business, when it finally develops that Congress recommended it, or the President recommended it in his message, then that is another day. But I do seriously object personally—and I am not speaking for the committee—to having new ideas continually coming out where lack of experience is obvious, that upset the entire situation or the peace of mind of the people who are in the business—just as I said the other day. I am still firmly of the opinion that you are the best Depart-

ment in the country in inventorying known mineral resources, but to go further and say that there is no more mineral in the country and that we must import this mineral is entirely beyond the prerogatives of the Department of the Interior.

Mr. LEE. I think, Senator, you misinterpret my statement.

Senator MALONE. No, you did not say that. I am now referring to statements that have been made over a period of 10 years that we are a "have-not" Nation. I am not convinced that we are a have-not Nation, and I don't think you are either.

Mr. LEE. No, I am not.

Mr. BOYD. If I may just reiterate for a second, Senator, that the Secretary mentioned to you that that is the firm position of the Department. They have the same objectives as the committee, the development and improvement of our standard of living through the production of basic raw materials and national security—I think I probably put that in reverse, and national security should be first—and anything that could be done to further that should be brought to the attention of the Congress, at your request.

Senator MALONE. It is not your idea that it is the prerogative of the Bureau of Mines to continually broadcast information that because the known supply, the inventory supply of one mineral is only 2 or 3 or 4 years, we should immediately start importing this mineral and let ours stay in the ground?

Mr. BOYD. That is certainly not my idea.

Mr. LEE. One more question that I don't think has been sufficiently brought to the attention of the committee, from a larger point of view of mineral exploration areas, for example, which we would call lead and zinc areas, Joplin, Mo., which at one time furnished most of our lead and zinc ore; that territory as a whole is down at the heel and the Geological Survy and the Bureau of Mines and our organization would like to do some real resuscitation, some real hard teamwork in that area, because that whole territory is going so far back that I am afraid the whole area will close down.

Senator MALONE. Speaking as one member of the committee, I thoroughly agree with you, that the prerogative of the Bureau of Mines is to assist in every way to explore the field. I think they have done a good job in that field, and I want to say again that there are some of the best technicians in the Bureau of Mines and in the United States Geological Survey that are in the country, and they are capable of doing a fine job. The thing to be decided, and which must be decided in the Congress of the United States and in the executive departments, is the extent to which the work can be carried on. That is the reason, one of the reasons, that I have asked for this information so it will be available.

Would you like to submit a statement for the record, Dr. Boyd?

Mr. BOYD. I think perhaps, Senator, it would help, and I would like to have that privilege.

(The matter referred to follows:)

There follow a few of the arguments for and against a change in the mineral leasing and mining laws in order to encourage the more rapid development of our mineral resources.

The arguments for leaving the mineral mining laws as they now exist are:

1. Inasmuch as the search for minerals is an exceedingly speculative business, there should be held out to the prospector a sufficient incentive to make it worth

his while. The present western mining laws covering the vein types of deposits provide that incentive by giving to the prospector full title to the minerals which he discovers on the public domain.

2. The mining laws of western United States have been established over a long period of time and after considerable years of litigation. Any serious change in this approach may well tend to inhibit mineral development rather than encourage it. The present method of locating land for mineral development on the public domain is well known in the West and its administration is relatively simple.

Those who have advocated the blanketing in of all minerals under the present leasing laws which now apply to the so-called blanket deposits—i. e., petroleum, potash, phosphate, coal, natural gas, sulfur, and sodium—argue (*a*) that is gives a monetary return to the taxpayers who are owners of the public domain; (*b*) it places in the hands of the Federal Government a greater flexibility for controlling the development of the minerals on the public domain in the national interest; (*c*) that it prevents the freezing of mineral lands in private hands and in small lots in perpetuity in such a way that the development of those areas is hindered at a time when the minerals should be freely exploited; (*d*) that by blanketing in these areas under the mineral leasing laws, prospecting permits may be obtained which will give organizations an opportunity to scientifically explore larger areas through geological and geophysical methods before they locate land to cover a specific mineral deposit.

Those that oppose the blanketing in of all mineral deposits under the leasing laws contend that the administration is necessarily so complicated that it takes too long to obtain a mineral lease during which time the enthusiasm for the development of the area is lost.

Senator MALONE. The committee will be very glad to have it.

Is there any further statement that anyone would like to make at this time, any of the witnesses that have appeared?

Mr. Miller, do you have anything further?

Mr. MILLER. I have nothing further, Senator, other than if at a subsequent date in your hearings you want further information from us I hope you will feel free to ask for it.

Senator MALONE. I am going to advise the committee that the entire facilities of the Bureau of Mines and the United States Geological Survey are at their service, if I may.

Mr. MILLER. Yes, Senator.

Senator MALONE. And I want to say again that I am deeply appreciative of the information you have submitted. I think it will be of value to the country, and I believe it will be of great value as a part of the work of establishing what this Nation can produce, and then proceeding from there. Certainly some of your men can help us in determining a course of action, especially if we can get more foreign information, and if you will, Mr. Miller, would you keep us advised as to any new information you discover in the foreign field, either from the RFC or from other departments of the Government?

Mr. MILLER. I will be glad to keep you up to date on that.

Senator MALONE. Then when we get to the point of determining differential costs, which I think is necessary within certain latitudes before it, Congress can decide on the principle—in other words, the necessary flexible import fees or tariffs that will bring about that balance between the standard of living in this country and that of the other 54 nations in the United Nations, which I am firmly of the opinion is necessary for our trade relations between these countries; because if we could get a more or less automatic method that could be carried out by the Tariff Commission, custom officials, or some other existing body, that would automatically determine the differential costs of production and let that determine the import fee or tariff.

Then as they raise their standard of living you can lower the import fee or tariff, and when the standard of living is about the same as ours, automatically free and unrestricted trade results. There is no question but what the objective of every nation—at least, I assume it is ours—is to reach a condition where we will have free trade and raise every other nation up to our standard of living, and raise our own if we can. It is only a question of how to reach that objective without interference with our economic structure.

People differ on methods. Some say take all tariffs and import fees off and have free trade and we will raise all these nations up to our standard of living. Others say we can't do that. I am making no statement at this time, because we are looking for the answers. We simply know the problem. We do not know the answers. But if we can first find out from these various fields, as I have often outlined here, the mineral field, the agricultural field, the forestry field—what commodities we can produce—then when we know within general latitudes the difference in cost of production between this country and the countries where the cheap competition is on each product, then and only then will we have a reasonable basis to get the answer. That is my personal opinion, not the opinion of the committee. It was not discussed with the committee.

Again I thank you very much, and we will now adjourn until 10 o'clock tomorrow morning.

Senator Malone. At the request of the committee, the Bureau of Mines has prepared a table showing United States and world production and prices for a certain list of metals and nonmetals covering the years 1944, 1945, and 1946. This table is submitted for the record at this point.

(Whereupon, at 12:10 p. m., the subcommittee adjourned until 10 a. m., Wednesday, May 21, 1947.)

Production and prices of certain metals and nonmetals

Commodity	Unit	Production: United States 1944	United States 1945	United States 1946	World 1944	World 1945	World 1946	Price (United States): Unit	1944	1945	1946
METALS											
Antimony (Sb. content)	Short tons	4, 735	1, 930	2, 505	37, 800	29, 200	27, 400	Cents per pound	15. 84	15. 84	17. 31
Arsenic (white—As_2O_3)	do	36, 094	24, 349	10, 211	72, 973	56, 879	36, 156	do	4. 0	4. 0	6. 0
Aluminum	do	776, 446	495, 060	409, 630	1, 915, 000	978, 000	827, 000	do	. 15	. 15	. 15
Bauxite (shipments)	Long tons	2, 698, 338	1, 071, 794	1, 018, 774	7, 024, 000	3, 642, 000	3, 937, 000	Dollars per long ton	6. 90	6. 93	7. 01
Cadmium	Pounds	8, 453, 470	7, 932, 579	5, 300, 000	11, 700, 000	12, 200, 000	12, 100, 000	Dollars per pound	. 93	. 93	. 93
Chromite	Long tons	40, 740	12, 476	3, 667	1, 427, 000	1, 083, 000	1, 083, 000	Dollars per long tons	40. 95	42. 67	28. 64
Copper smelter domestic ores)	Short tons	1, 003, 379	782, 726	599, 656	2, 900, 000	2, 400, 000	1, 900, 000	Cents per pound	[1] 11. 87 [3] 13. 6	[1] 11. 87 [3] 13. 6	[2] 13. 92 [3] 15. 72
Gold	Fine ounces	998, 394	954, 572	1, 574, 505	27, 070, 000	23, 930, 000	(4)	Dollars per ounce	35. 00	35. 00	35. 00
Iron ore	Long tons	94, 117, 705	88, 376, 393	70, 843, 113	203, 000, 000	157, 000, 000	144, 000, 000	Dollars per long ton	2. 70	2. 77	3. 07
Lead	Short tons	416, 861	390, 831	335, 475	1, 493, 631	1, 363, 559	1, 361, 354	Cents per pound	[1] 6. 5 [3] 8. 0	[1] 6. 5 [3] 8. 6	[2] 8. 1 [3] 10. 9
Manganese	Long tons	221, 084	162, 799	128, 245	2, 717, 000	3, 800, 000	(4)	Dollars per long ton	36. 41	44. 97	37. 52
Mercury	Flasks of 76 pounds	37, 688	30, 763	25, 348	165, 000	142, 000	139, 000	Dollars per flask	118. 36	134. 89	98. 24
Molybdenum (Mo content)	Short tons	19, 335	15, 401	9, 109	23, 479	17, 527	11, 023	Cents per U. MoS_2	45. 00	45. 00	45. 00
Nickel (metal)	Pounds	1, 976, 000	2, 310, 000	704, 000	360, 000, 000	338, 000, 000	280, 000, 000	Cents per pound	31. 5	31. 5	31. 5–35
Platinum metals	Ounces	40, 549	31, 046	26, 312	520, 000	971, 000	576, 000	Dollars per ounce refined platinum.	35. 0	35. 0	57. 20
Silver	Fine ounces	34, 473, 540	29, 024, 197	22, 914, 604	186, 200, 000	(4)	(4)	Cents per ounce	71. 1	71. 1	80. 8
Tin	Long tons	5			105, 000	87, 000	92, 000	Cents per pound	52. 0	52. 0	54. 6
Tungsten, shipments (metal)	Pounds	9, 786, 500	5, 266, 800	4, 942, 300	51, 405, 200	24, 129, 000	19, 933, 000	Dollars per short ton unit WO_3.	23. 35	23. 17	20. 17
Vanadium (V. content)	do	3, 527, 054	2, 963, 913	1, 272, 148	6, 069, 000	5, 244, 000	2, 356, 000	Cents per pound V_2O_5 in ore.	27. 5	27. 5	27. 5
Zinc	Short tons	718, 642	614, 358	574, 833	1, 861, 803	1, 418, 674	1, 479, 301	Cents per pound	[1] 8. 3 [3] 11. 4	[1] 8. 3 [3] 11. 5	[2] 8. 7 [3] 12. 2
NONMETALS											
Asbestos	do	6, 667	12, 226	14, 075	(4)	(4)	(4)	Dollars per short ton	57. 05	36. 48	35. 86
Fluorspar (shipments)	do	413, 781	323, 961	277, 940	1, 197, 110	(4)	(4)	do	30. 22	30. 55	32. 52
Mica—strategic mica only		(4)	(4)	(4)	(4)	(4)	(4)		(4)	(4)	(4)
Nitrogen-chemical	Short tons	1, 212, 407	1, 061, 666	857, 173	(4)	(4)	(4)		(4)	(4)	(4)
Phosphate rock	Long tons	5, 376, 643	5, 806, 723	6, 860, 713	(4)	(4)	(4)	Dollars per long ton	3. 88	4. 12	4. 52
Potash	Short tons	817, 892	870, 370	928, 374	(4)	(4)	(4)	Dollars per short ton	36. 05	34. 83	34. 66
Sulfur	Long tons	3, 218, 158	3, 753, 188	3, 859, 642	3, 444, 688	4, 035, 205	(4)	Dollars per long ton	16. 00	16. 00	16. 00
Pyrites	do	788, 530	722, 596	813, 372	6, 889, 375	5, 905, 179	(4)	Cents per long ton unit for imported Spanish.	14. 00	14. 00	14. 00

[1] OPA ceiling price. [2] Without bonus payments. [3] With bonus payments. [4] Not available.

Source: Prepared by Economics and Statistics Branch, Bureau of Mines, Oct. 6, 1947.

APPENDIX

MINERAL POSITION OF THE UNITED STATES

BY

THE STAFFS OF THE BUREAU OF MINES
AND GEOLOGICAL SURVEY

FOREWORD

The United States has been endowed with vast mineral resources, whose equal in quantity and variety has not yet been found in any other like area of the world. Possession of these resources and ability to utilize them have made possible the preeminent industrial position of the United States and its unexcelled standard of living. Our deposits of coal, iron ore, petroleum, and many other minerals essential to our industrial civilization thus comprise one of the Nation's greatest assets, vital to every citizen in the land.

Mineral resources are, unfortunately, exhaustible, and through the years they have been depleted at an ever-increasing rate. During the recent war, the United States was hard pressed to obtain mineral raw materials adequate to meet military and civilian requirements. Once again, it was evident that the Nation's storehouse of minerals lacked several important commodities without which our industrial machine could not function. Some of the mineral industries, from which ample supplies were derived in the past, were unequal to the task of meeting the war-inflated demand. These experiences naturally caused anxiety as to the extent to which the mineral resources of the Nation had been exhausted.

The United States Department of the Interior, being charged with the responsibility of promoting the conservation and development of the country's natural resources, is deeply concerned about the status of the mineral industries of the Nation. Recognizing the need for taking stock and appraising the outlook for the future, the Department, through its Bureau of Mines and Geological Survey, undertook an appraisal of the United States mineral position early in 1944. The results of the study are presented in this volume.

The report reveals that the United States is by no means a "have-not" nation in those minerals that are basic to the maintenance of its kind of industrial society. However, its resources are deficient in several important industrial minerals and the outlook for major improvements in most of these areas is not favorable. Thus, continued dependence on foreign sources for supplies of these commodities is indicated. Although the group includes minerals that are vital to the machine economy, in the past it has represented dollarwise a minor part of our mineral requirements. This country can maintain varying degrees of self-sufficiency in a third group of minerals which includes some in which virtual independence from foreign sources has been enjoyed for several decades. In some of the minerals of this group the effects of depletion of known resources are being reflected in production patterns where deficiencies exist or are developing. Steps must be taken to insure adequate supplies in times of emergency.

In general, America's mineral outlook is favorable, but it is obvious that a dynamic program of research and exploration must be pursued if new sources are to be developed to supply future needs. This Nation can no longer afford to continue the policy of letting nature take its course.

The data presented in this report are not to be taken as a measure of the Nation's ultimate mineral wealth. Such an appriasal is precluded at this time by incomplete knowledge of the country's resources. The report does present a factual summary of the present mineral position of the United States based on present knowledge. It is believed that the study will prove to be a valuable guide to legislators, Government officials, producers and consumers of minerals, and others concerned with problems of mineral supply.

J. A. Krug,
Secretary of the Interior.

MEMORANDUM OF TRANSMITTAL

Memorandum to Dr. R. R. Sayers, Director, Bureau of Mines; Dr. W. E. Wrather, Director, Geological Survey.

Transmitted herewith is a report entitled "The Mineral Position of the United States," prepared in response to a request from the Director of the Bureau of

Mines and the Acting Director of the Geological Survey, dated December 31, 1943. The work is the result of cooperative effort by the staffs of the Geological Survey and the Bureau of Mines. It includes 39 commodity chapters, containing estimates of reserves in known domestic deposits and other economic data for most of the important mineral raw materials used by industry in the United States. These comprise the major contribution of the study.

The significance of mineral-reserve estimates must be evaluated in the light of the inadequacy of available information on mineral resources and the potential influence of scientific, technologic, and economic changes on the discovery and exploitation of mineral deposits. Consideration of these points is essential to proper interpretation of each of the 39 commodity-reserve estimates. However, to avoid repetition in the commodity chapters, discussion of these factors has been centralized in three introductory chapters entitled "Method of Preparation and Limitations of Report," "Deficiencies in Data on Mineral Resources," and "Trends in Technology and Outlook for Improvement in Mineral Position." The committee emphasizes the importance of careful study of these chapters in interpreting the mineral-reserve estimates. The report also includes an introductory chapter presenting background information on the history of the development of the mineral industries in the United States and a summary of the significant facts developed by the study.

We believe that information of the type in this report is of interest and value to policy-making agencies of the executive and legislative branches of Federal and State governments, producers and consumers of mineral raw materials, and the general public. Because of the critical position occupied by mineral resources in current history, these data are particularly significant at this time. Therefore we recommend that the report be printed for public distribution at the earliest possible date. We recommend further that the mineral reserves of the United States be reestimated from time to time as new information on resources becomes available.

The committee desires to acknowledge, with appreciation, the cordial cooperation of all members of the staff of the Bureau of Mines and the Geological Survey who took part in the preparation of the report, including many who do not appear as authors. Particular acknowledgment is made of the contributions of D. F. Hewett and E. B. Eckel, of the Geological Survey, who served as members of the committee before official duties necessitated their departure from Washington. To D. F. Hewett special credit is due for invaluable counsel throughout the study.

INTERBUREAU COMMITTEE FOR MINERAL RESERVES STUDY.

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MINERAL POSITION OF THE UNITED STATES

By the staffs of the Bureau of Mines and the Geological Survey

INTRODUCTION

The purpose of this report is to make available, to the legislative and executive branches of Federal and State Governments and others interested in the problem of mineral supply, an objective appraisal of the mineral-resource position of the United States. Such information is needed by the Congress, the United States Tariff Commission, the United States Department of State, conservation agencies, regional planning authorities, and State legislatures and mining bureaus. Although not specifically designed for those in industry, the appraisal should be useful to them, particularly to producers and consumers of metals and minerals.

Today, as in the past after every period of abnormal drain upon the Nation's mineral resources, anxious questions are being asked concerning its degree of self-sufficiency and the possible duration of such self-sufficiency. There is no single or simple answer to such questions. The situations with respect to different commodities are too diverse and complex. For some commodities the United States depends completely on foreign sources, whereas for others it is completely self-sufficient; for most, the situation lies somewhere between these two extremes. The United States learned in the First World War that it was deficient in several essential metals and minerals, and the tremendous increase in annual rates of consumption since then has aggravated these deficiencies. In addition, technologic advances, including changes in use patterns, have resulted in the addition of several other minerals and metals to the list of indispensable raw materials; of these, some are found in adequate quantity and quality at home, some are not. The tremendous demands of the war just ended and the new technical developments stimulated by the war have still further complicated the situation and aroused a national interest where before only a few individuals had shown concern.

With a view to summarizing and analyzing the data available, the Bureau of Mines and the Geological Survey of the United States Department of the Interior undertook a quantitative appraisal of the mineral-resource position of the Nation. The Department at present is in a better position to make such a study than at any other time in its history. Under the Strategic Minerals Act of 1939, the Bureau of Mines and the Geological Survey began an intensive search for new and marginal sources of supply of the seven metals specified at that time by the Army and Navy Munitions Board as strategic—antimony, chromium, manganese, mercury, nickel, tin, and tungsten. Late in 1941, again under specific act of the Congress, they began an investigation of western iron deposits. In 1942, by further congressional authority, they enlarged the scope of their work to cover all mineral commodities needed in the war effort, about 53 in number. This work continued through 1944.

In the course of this intensive 5-year effort, the Geological Survey and the Bureau of Mines amassed more data on mineral deposits than had ever before been assembled in our group. This information, supplemented by considerable data made available to them from other sources, forms the basis of the commodity studies presented herein. The inquiry was initiated early in 1944, but many unanticipated developments, mostly urgent war-created assignments for part of the staff, have delayed its completion. Most of the reserve estimates were made in 1944, but changes in the mineral industry as a whole since then have been small, and it is believed that if the figures were corrected for early 1947 there would be few, if any, significant changes.

The present effort at appraising the mineral-resource position of the Nation is the most comprehensive yet attempted. One early effort was Bulletin 394 of the Geological Survey, published in 1909 as a reprint of selected papers written

for the report of the National Conservation Commission (S. Doc. 676, 60th Cong., 2d sess.). Another was Geological Survey Bulletin 599, entitled "Our Mineral Reserves," by George Otis Smith, which appeared in 1914, although this report was more in the nature of an analysis of the state of industrial affairs at that time than an estimate of reserves. Various persons and groups in and out of Government service have made regional and national reserve studies of individual commodities from time to time since then; and various agencies representing private industry, most notably the American Petroleum Institute, make national estimates for the commodities within their interest. The present report, however, is the first attempt at an over-all appraisal of the Nation's mineral wealth—its magnitude and degree of adequacy. It may be noted, as a measure of the expanding use of metals and minerals, that whereas the first national appraisal mentioned above (Geological Survey Bulletin 394) discussed 10 commodities, and the second (Geological Survey Bulletin 599) gave major attention to 24, the present report discusses 39.

In 1936, the National Resources Committee issued a comprehensive report, The Mineral Reserves of the United States and Its Capacity for Production, by K. Leith and D. M. Liddell.

In undertaking this task, the Bureau of Mines and Geological Survey have been fully aware of the limitations of such a study and of the danger that the results may be misinterpreted or mistakenly applied, but they believe that the usefulness of the results more than outweighs such considerations.

Because of the hidden nature of mineral deposits, reserves can never be appraised with any degree of finality; but estimates based on such data as are available, made by qualified experts, provide a guide for proper understanding of the mineral-resource problem and for the formulation of sound national policy. The limitations of the report and the nature of the data on which the reserve estimates are based are discussed in detail in separate chapters.

This is a pioneer effort in a difficult field; if it meets satisfactorily the purpose for which it is intended, we hope it can be brought up to date from time to time as need demands and as information permits. If the Nation is to look ahead and plan wisely, it must have a continuing authoritative appraisal of its natural resources.

R. R. Sayers,
Director, Bureau of Mines.
W. E. Wrather,
Director, Geological Survey.

SUMMARY

By Samuel G. Lasky[2] and E. W. Pehrson[3]

The mineral resources of the United States are among the Nation's outstanding assets. They are the foundation that supports its great industrial economy, making possible a high standard of living and present leading position in world affairs; however, facts not widely recognized by laymen are that mineral deposits are exhaustible, and that this mineral wealth has been depleted at an ever-increasing rate.

Although minerals were extracted and used on a small scale by the early colonists and output increased steadily as the Nation developed, the major initial impetus to production was the industrial expansion during the latter part of the nineteenth century. By 1880 the annual value of minerals produced in the United States had reached $367,000,000; but by 1907 it had exceeded $2,000,000,000, and in 1944 reached the unprecedented total of $8,500,000,000. Even this record was exceeded in 1946, when production was valued at nearly $9,000,000,000.

The twenty-two-fold increase in output since 1880 and the difficulties of obtaining adequate mineral supplies during the recent war emphasize the exhaustible nature of mineral resources. Because minerals are so essential to the economic security of the Nation and to the national defense, a realistic appraisal of America's present position in minerals and of its future outlook is vital to Government, industry, and the public.

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[2] Principal geologist, Geological Survey.
[3] Chief, Economics and Statistics Branch, Bureau of Mines.

This report analyzes the situation for 39 of the more important mineral raw materials used in industry. Such minerals as sand, gravel, limestone, building stone, slate, clays, feldspar, and those used as fillers, of which the United States has ample supplies, are not included in the study.

Present Position in Mineral Supply

Describing the mineral position of a nation in terms of its self-sufficiency or its ability to produce to meet its own needs is a well-established practice. Self-sufficiency is readily and effectively determined by comparing production and consumption during a chosen period, for such a comparison considers all the factors—resource, technologic, and economic—that influence the production that develops in response to a specific demand. For most commodities the basic factor is the quantity of the raw-material resource—the reserves—exploitable under prevailing conditions, particularly the spread between cost and price. Under special circumstances other factors, such as availability of labor and equipment and the limitations imposed by installed capacity, are equally important. Also, with the byproduct materials, output frequently is restricted more by the rate at which the associated metals or minerals are produced than by the size of the reserve or by other factors. However, the influence of factors other than reserves usually is relatively temporary, so that, for long periods, the degree of self-sufficiency provides a rough measure of the economic availability of resources.

Figure 1 compares the self-sufficiency of the United States in 39 important

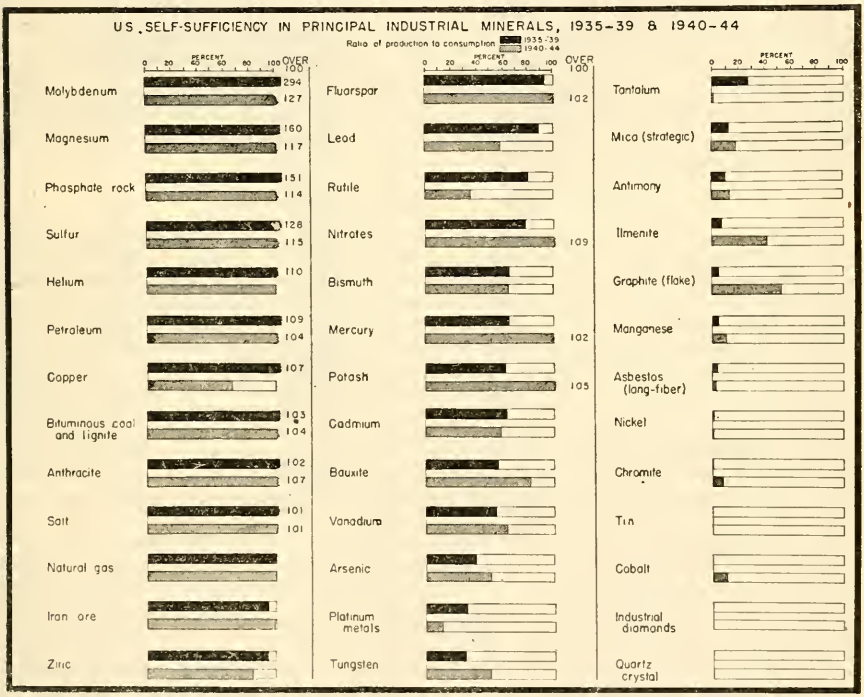

FIGURE 1.—Production of principal industrial metals and minerals in the United States expressed in percentage of domestic consumption, 1935–39 and 1940–44.

industrial minerals during the 5-year periods 1935 to 1939 and 1940 to 1944. Before the war, production equaled or exceeded consumption in 11 commodities. For 12 minerals, production ranged from 50 to less than 100 percent of consumption, for 6 commodities from 10 to less than 50 percent, and for 10 minerals less than 10 percent of requirements. During this period, there were few if any labor or equipment shortages or restraints imposed by production facilities.

Thus, except for the byproduct minerals, the production record affords a fairly reliable index of the availability of domestic resources under the economic and technologic conditions prevailing at that time.

It will be noted that, from 1935 to 1939, the United States was fully or highly self-sufficient in coal and iron ore, the raw materials required to support an industrial economy based on steel. It was equally well situated with respect to supplies of other important minerals, such as petroleum, copper, sulfur, and phosphate rock. However, the record also reveals that this country depended on foreign sources for substantial proportions of its needs of other minerals that are indispensable in this machine age.

During the war there were notable increases in the ratio of production to consumption in some minerals and decreases in others. Significant improvement in self-sufficiency was obtained in iron ore, fluorspar, nitrates, mercury, potash, bauxite, vanadium, arsenic, tungsten, ilmenite, and flake graphite, whereas dependence on foreign sources of copper, zinc, lead, rutile, platinum metals, and tantalum increased substantially. It should be noted, however, that flake graphite produced during the war was substandard and unsuitable for some important uses.

On the whole, there was only a moderate improvement in American self-sufficiency during the war. In view of the tremendous need for minerals for the war program and the pressure for larger output, a more striking result might have been expected. Failure to achieve a larger measure of self-sufficiency under these conditions may be ascribed to many factors. Lack of reserves precluded significant production of many minerals, including chromite, nickel, tin, industrial diamonds, and quartz crystals. For some of the other metals and minerals, depletion of the reserves undoubtedly was an important but by no means solitary factor. During the war, shortages of manpower and equipment and the limitations of installed production capacity were real bottlenecks that prevented full realization of the reserve potential. Opinions differ as to the relative importance of these causes, but the fact remains that the war experience demonstrated weaknesses in the Nation's mineral position and emphasized the need for doing something about it.

Magnitude of "Commercial" Reserves

Owing to the nature of mineral occurrence and the relatively small quantity of available information on the economic geology of the United States, it must be recognized that present knowledge of the country's mineral resources represents only a fraction of that needed for a comprehensive and reliable appraisal of our ultimate mineral wealth. Conseqeuntly, the data on resources presented in this report are restricted to deposits in known mineralized areas as appraised on the basis of current information. No allowances have been made for future discoveries in new areas. The quantitative estimates presented herein include measured, indicated, and inferred reserves, as defined elsewhere in this study. Inferred reserves comprise material of which there is little if any visual evidence, although its occurrence can reasonably be inferred from geologic evidence. Many of the estimates include substantial proportions of inferred ore, so that, in general, they are considerably more inclusive than those ordinarily used in commercial practice.

Resources are classified further as commercial and submarginal. For the purpose of this report, commercial reserves are broadly defined for most minerals as material available under the economic and technologic conditions prevailing in 1944. For a few minerals, estimates were based on good prewar conditions. Submarginal resources include deposits that cannot be exploited with monetary profit, except under more favorable economic conditions, improved technology, or both. Because the estimates of commercial reserves have been based on economic conditions considerably more favorable than the average prevailing in the past, the term "commercial" has been used broadly and should not be interpreted as implying that the reserve is commercially available in the sense in which the term usually is employed. In the accompanying illustrations, the word "commercial" has been set off in quotation marks to indicate that it has been used in a qualified sense.

Figure 2 compares the estimated commercial reserves of 41 commodities in known deposits with the average annual production and consumption during the decade 1935 to 1944. The reserves of 15 of the minerals shown in the graph are equivalent to more than half a century of requirements at the 1935–44 rate of

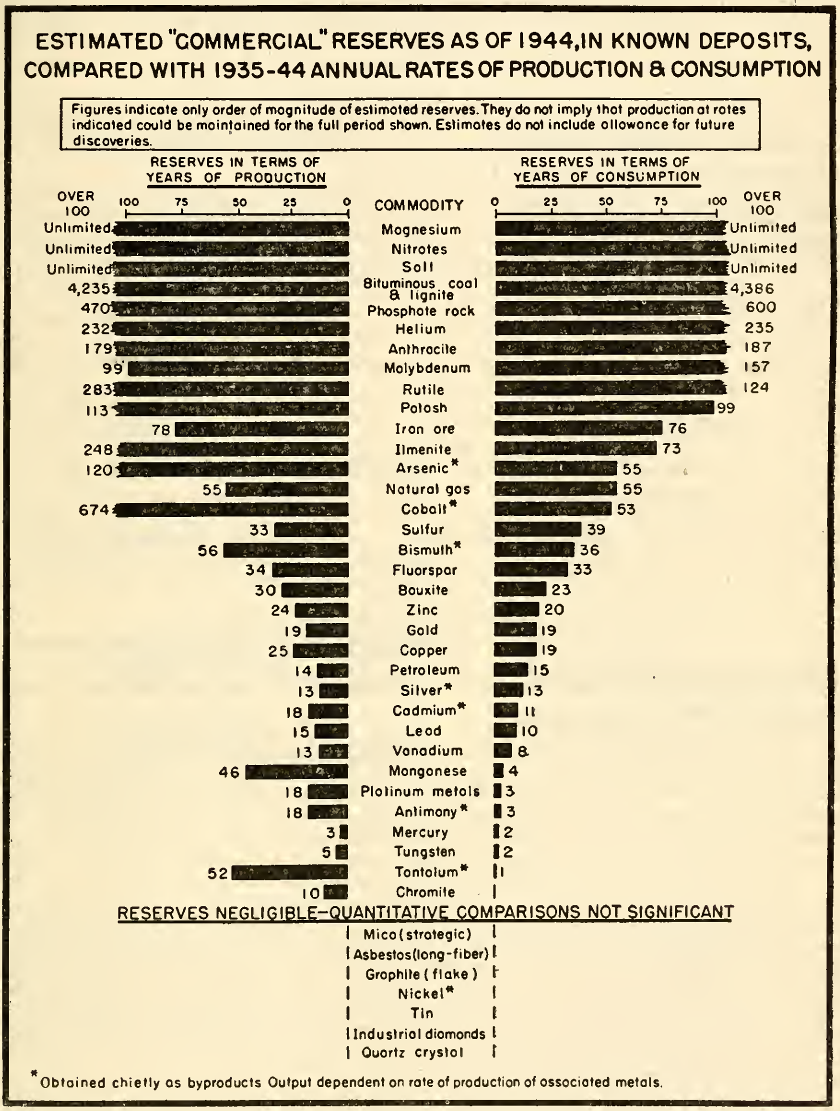

FIGURE 2.—Estimated "commercial" reserves in known deposits in the United States compared with average annual rates of domestic production and consumption, 1935–44.

consumption. This group includes coal and iron ore and the fertilizer minerals, phosphate rock, potash, and nitrates. The reserves of magnesium, derived chiefly from sea water and underground brines, are virtually unlimited. This is true also of nitrates, obtained from atmospheric nitrogen, and of salt, available in vast underground deposits and in sea water. The United States has a monopoly on commercial supplies of helium, and the known reserves are relatively large in terms of the rate at which it has been used. The United States also produces most of the world's molybdenum, and the reserve position is favorable. This country

has sizable reserves of the titanium minerals, rutile and ilmenite, but heretofore they have supplied only part of its needs.

The estimated commercial reserves of three minerals—sulfur (all forms), bismuth, and fluorspar—are equivalent to 33 to 39 years of supply at the average rate of use from 1935 to 1944, and those of the remaining 23 commodities shown in figure 2 are equivalent to less than 25 years. This group includes such highly essential minerals as bauxite, zinc, copper, petroleum, lead, most of the ferro-alloying minerals, tin, and several nonmetallic minerals that have very important uses.

Attention is called to the fact that the estimates of natural-gas and petroleum reserves contain only "proved" reserves. If estimates also included the indicated and inferred categories, these two commodities would doubtless occupy a much more favorable position in the chart.

The size of the reserves, in terms of past production, presents a somewhat different pattern. Since the United States produced considerably more phosphate rock, molybdenum, and sulfur than it consumed during the decade the size of the reserves in years of production is substantially less than in years of consumption. To a smaller extent the same is true of bituminous coal and lignite, anthracite, helium, and petroleum, of which America was a net exporter from 1935 to 1944.

Production and consumption of natural gas were about equal during the 10-year period. Because the monetary status of gold and silver provides a ready market for all that is produced, for the purposes of figure 2 consumption of these metals was considered equal to the production. Consequently, the size of reserves of natural gas, gold, and silver is the same whether computed on the basis of consumption or of production. Production of all other commodities shown in the chart was less than the consumption in varying degrees; for this reason, the reserve expressed in years of production is larger than when expressed in years of consumption. The great disparity shown for cobalt is due to the fact that production represented a very small fraction of the consumption. The lack of sizable production was due to the limitations imposed by the by-product nature of cobalt in much of the reserve and the economic unavailability of other portions of the reserve. Commercial reserves of manganese and tantalum are relatively very small; but the output also has been small, so that in terms of years of production the reserve appears to be relatively large.

The commercial reserves of strategic mica, long-fiber asbestos, flake graphite, nickel, tin, industrial diamonds, and quartz crystal either are nonexistent or so small that quantitative comparison with past production and consumption would have no significance.

Figure 3 shows the percentage of measured, indicated, and inferred reserves included in the total estimates of commercial reserves and reflects the relative certainty of the various reserve estimates. The estimates for helium, anthracite, bituminous coal and lignite, magnesium, natural gas, petroleum, phosphate rock, nitrates, and salt consist entirely of measured reserves. Consequently, the physical availability of these reserves to the extent shown in figure 2 is virtually assured, although varying degrees of risk attach to their commercial availability. A very large proportion of the molybdenum reserve is in deposits where the quantity available can be measured. For several commodities, it was not possible from the nature of the information available to differentiate between measured and indicated reserves. Antimony, bauxite, cobalt, copper, iron ore, lead, gold, platinum metals, potash, zinc, mercury, and silver are included in this group. Measured and indicated reserves represent well over 50 percent of the total estimate for all of these minerals except cobalt, lead, gold, platinum metals, zinc, and mercury. The degree of dependence that can be placed on the availability of the estimated reserves declines as the proportion of total reserve in the measured and indicated categories decreases.

In estimating the mineral reserves of arsenic, bismuth, cadmium, manganese, and sulfur, it was impossible to differentiate between measured, indicated, and inferred material. The uncertainty involved in estimates of this kind obviously is greater than that pertaining to measured and indicated reserves. The greatest hazard attaches to inferred material, and attention is called to the large proportion of this class of reserve in the estimates for chromite, cobalt, fluorspar, iron ore, lead, gold, platinum metals, tantalum, rutile, tungsten, vanadium, zinc, and mercury. However, the uncertainty in mineral-reserve estimates resulting from the inclusion of large proportions of inferred ores is, in a sense, offset by the fact that no allowance has been made for future discoveries in the reserve estimates.

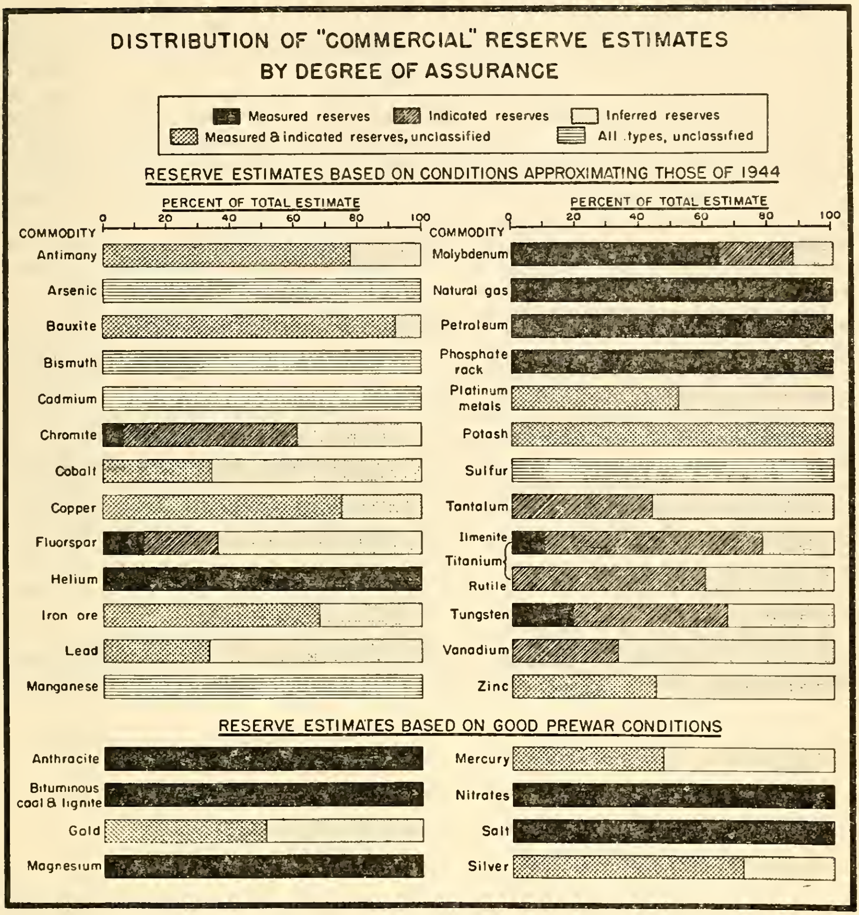

FIGURE 3.—Percentage of measured, indicated, and inferred reserves included in total estimates of "commercial" reserves in known deposits in the United States.

FUTURE OUTLOOK

Analysis of known commercial reserves in the United States indicates that this country is exceptionally well-supplied with coal and reasonably well off in iron ore, so that the Nation is not confronted with a scarcity of raw materials that could threaten the basic security of its steel industry. Thus the foundation of its industrial economy is assured for many decades. It is true that known reserves of high-grade coking coal are becoming scarce and that the more readily available high-grade iron ores are nearing exhaustion, but there are tremendous lower-grade resources that should offer no insurmountable difficulty to utilization. The relatively large reserves of potash, phosphate rock, and nitrates that are available in unlimited quantity will protect the fertilizer needs of the Nation for many years. However, based on present knowledge, the outlook for many other important mineral raw materials is not so favorable. The extent to which the situation in these commodities may be improved depends upon the success achieved in discovering new deposits in the future and in overcoming the technologic and economic barriers to the utilization of known submarginal resources.

Opinions differ on the outlook for an improved position in minerals through discovery of new deposits. Geologists in general believe that reserves in addition to those estimated will be found in present producing areas and in areas adjoining them as known deposits are worked out. They also are confident that the development of new techniques for ore finding will make possible larger-scale discovery in areas not now productive. On the other hand, the fact that the United States has been heavily prospected by traditional methods so that most of the easily discovered deposits already have been found and the slowing up of discovery in recent decades leads some students of the resource problem to hold a contrary view. In their judgment, the capital risks involved in exploring for hidden ore bodies on geological or geophysical inference will discourage large-scale prospecting. Nevertheless, there is general agreement that the search for new mineral deposits must be pushed vigorously but that meanwhile other national policies should be based on the known resources.

The Nation's submarginal resources offer an additional base for improving its mineral position. With modern research techniques, many of the problems involved in employing some of them can be solved in a relatively short time. The technologic advances that have made it possible to utilize resources previously considered worthless are likely to be matched by similar gains in the future—any assumption to the contrary underestimates the potentialities of engineering and metallurgical research. Progress in technology can increase the availability of those minerals that already are widely used and bring into service some of the more plentiful elements in the earth's crust that as yet have not been extensively employed in industry. Research can point the way to changes in trade practices that will make possible economic use of domestic resources not suited to present industrial processes, and the conversion of submarginal resources to commercial reserves will stimulate the search for new deposits. However, large submarginal resources are not known for all of the deficient minerals.

Figure 4 presents, in a generalized manner, the United States mineral position based on the outlook for future discovery and on the possibility that technologic and economic changes will permit use of known submarginal resources.

U. S. MINERAL POSITION—ACTUAL, IMPENDING, AND POTENTIAL

Based on known "commercial" reserves, outlook for noteworthy discovery, and the possibility that known submarginal resources can be made available by technologic progress and improved economic conditions

RELATIVE SELF-SUFFICIENCY

ACTUAL AND IMPENDING

(Based on present technologic and economic conditions and on known "commercial" reserves)

A. VIRTUAL SELF-SUFFICIENCY ASSURED FOR A LONG TIME:

Bituminous coal and lignite	Magnesium	Fluorspar (metallurgical)
Anthracite	Molybdenum	Helium
Natural gas		Magnesite
		Nitrates
		Phosphate rock
		Potash
		Salt
		Sulfur

B. COMPLETE OR VIRTUAL DEPENDENCE ON FOREIGN SOURCES:

1. Small or remote expectation of improving position through discovery:

	Chromite	Industrial diamonds
	Ferro-grade manganese	Quartz crystal
	Nickel*	Asbestos (spinning-quality)
	Platinum metals	
	Tin	

2. Good expectation of improving position through discovery:

	Cobalt*	Graphite (flake)

C. PARTIAL DEPENDENCE ON FOREIGN SOURCES, ACTUAL OR IMPENDING:

1. Good expectation of improving position through discovery:

Petroleum	Arsenic*	Fluorspar (acid-grade)
	Bismuth*	
	Cadmium*	
	Copper	
	Iron ore	
	Lead	
	Mercury	
	Tantalum*	
	Tungsten	
	Zinc	

2. Little hope of improving position through discovery:

	Antimony*	High-grade bauxite
	Vanadium	Strategic mica

*Domestic production chiefly byproduct.

POTENTIAL

(If technologic and economic changes permit use of known submarginal resources)

A. VIRTUAL SELF-SUFFICIENCY:

Bituminous coal and lignite	Aluminum ores	Fluorspar (all grades)
Anthracite	Copper	Graphite (flake)
Natural gas	Iron ore	Helium
Petroleum	Magnesium	Magnesite
	Manganese	Nitrates
	Molybdenum	Phosphate rock
	Titanium	Potash
	Vanadium	Salt
		Sulfur

B. COMPLETE OR VIRTUAL DEPENDENCE ON FOREIGN SOURCES:

	Platinum metals	Industrial diamonds
	Tin	Quartz crystal
		Asbestos (spinning quality)

C. PARTIAL DEPENDENCE ON FOREIGN SOURCES:

	Antimony	Strategic mica
	Arsenic	
	Bismuth	
	Cadmium	
	Cobalt	
	Chromite	
	Lead	
	Mercury	
	Nickel	
	Tantalum	
	Tungsten	
	Zinc	

FIGURE 4.—United States mineral position; relative self-sufficiency of principal metals and minerals.

Materials in group A in the left column are those in which virtual self-sufficiency is assured for a long time. Since these present no serious problem for the immediate future, there need be no concern with the outlook for future discovery or the utilization of submarginal resources.

Group B in the left column includes the metals and minerals for which the United States is completely or virtually dependent on foreign sources for supplies. For only two of the commodities in this group—cobalt and flake graphite—do geologists believe that there is good expectation for substantial improvement in our position through discovery; for the others, although search must be continued, the Nation probably must resign itself to permanent domestic deficiency.

Group C in the left column comprises the mineral commodities for which the Nation already depends, or within a few years will depend, on imports for at least a part of its needs. For some of these—including such important materials as petroleum, copper, lead, zinc, tungsten, and mercury—geologists believe there is good expectation of discovering new domestic sources; for others they believe there is little hope.

The right column indicates the extent to which the Nation's mineral position could conceivably be changed through technologic process and improved economic conditions. Petroleum, vanadium, manganese, ores of aluminum, flake graphite, and strategic mica are outstanding examples of materials known to be present in such quantities that the Nation could be made self-sufficient in them if they could be mined and processed profitably. For a few others—mercury and tungsten in particular—the submarginal resources are large enough to bring about at least moderate improvement in resource position if they could be made available.

Attention is called to the position of petroleum in the potential self-sufficiency group. Not only is the outlook for improving our present reserve position in this vital raw material through discovery good, but research on methods of converting natural gas, coal, oil shale, and oil lands into liquid fuels may shortly make these resources available as substitute sources of petroleum products.

Gold and silver have not been shown in either column because there is no satisfactory measure of their self-sufficiency.

METHOD OF PREPARATION AND LIMITATIONS OF REPORT

By Samuel G. Lasky [4]

The body of this report consists of estimates of reserves for the more important metals and minerals used in American industry, presented in 39 individual commodity chapters. Each such chapter includes also statements on the uses of the commodity, possible substitutes, the economic setting, and—where the situation calls for it and the data permit—the adequacy of the reserves in terms of productive capacity and possible rates of production under various economic and technologic conditions.

To make the reserve estimates most understandable and usable, this report contains also a number of general prefatory chapters in which the economic and technologic factors that influence mineral position are discussed in greater detail from the national viewpoint as applied to the mineral industry as a whole. Whether a commodity is or is not a deficient one, the effect of possible discovery and changing economics and technology must be considered in appraising the resource position of the Nation as contrasted with the simple mathematical appraisal of reserves. The report includes also a historical review of the development of the mineral industry in the United States and an interpretive summary of the reserve data presented in the commodity chapters.

The preparation of the individual commodity chapters was assigned jointly to (*a*) the geologist administratively in charge of the work of the Geological Survey in that commodity or to some other geologist who had specialized in it, (*b*) the mining engineer in charge of the work on that commodity by the Bureau of Mines, and (*c*) the mineral economist of the Bureau of Mines who had specialized in that commodity. Thus, the data have been collected, analyzed, and interpreted by specialists in three of the principal phases of the mineral-resource problem.

To facilitate analyzing and interpreting the data and to acquire a uniformity of presentation, a common concept of reserves had to be adopted, for the term "reserves" is used differently by different persons, depending upon their peculiar

[4] Principal geologist, Geological Survey.

past experiences and upon their special fields of interest. For example, reserves mean something different to the man interested in such a commodity as aluminum or magnesium, where the exhaustibility or abundance of the resource depends upon the ingenuity of the technologist, and to the man interested in copper, lead, or zinc, of which the known supply is more measurably finite. They mean something still different to the man interested in tin or quartz crystal, of which the United States has virtually none, or to the man interested in such byproduct metals as cadmium, bismuth, or silver. Nevertheless, the diverse meanings should lie within the scope of a basic concept; otherwise, a common meeting ground and a standard for exchange of thought are lacking. The concept adopted for this report embodies the following principles:

1. There is a distinction between (*a*) the total material in the ground, (*b*) the portion thereof in bodies of such size, grade, purity, and geologic and geographic distribution as to suggest that it might be exploited in the foreseeable future—total reserves, and (*c*) the portion of the latter that can be mined and processed. In the various commodity chapters, the last category is spoken of as being "available" under the conditions specified, a distinction being made between material of commercial interest at the moment and material that is not.

2. Estimates of reserves and reserves themselves are fluctuating quantities. Total reserves in the ground fluctuate with changes in the foreseeable future and with depletion; estimates of such material change also with discovery and with new information in general. Available reserves fluctuate not only with depletion, discovery, and new information, but also with the ever-changing impact of mining technology, milling technology, cost and price, and possible acts of management.

3. Because they fluctuate, estimates of reserves are valid only for the date on which they are made and under the technologic and economic conditions specified.

4. The quantitative significance given unexposed ore depends on the purpose of the appraisal and the peculiar circumstances surrounding the particular commodity. It depends also as much on the convictions of the appraiser as on his judgment.

The reserve estimates are based on (*a*) direct field observation and study by personnel of the Geological Survey and Bureau of Mines, (*b*) records of other Government agencies, (*c*) published reports of mining companies, (*d*) information furnished directly by operators, and (*e*) technical and trade journals. The files of the various wartime agencies contained information rarely available to the Government in peacetime.

The reserves are classified as "measured," "indicated," and "inferred," according to the following definitions:

Measured reserves are those for which tonnage is compared from dimensions revealed in outcrops, trenches, workings, and drill holes and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are spaced so closely and the geologic character is so well defined that size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within limits which are stated, and no such limit is judged to be different from the computed tonnage or grade by more than 20 percent.

Indicated reserves are those for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to permit the mineral bodies to be outlined completely or the grade established throughout.

Inferred reserves are those for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition, of which there is geologic evidence; this evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred reserves should include a statement of the special limits within which the inferred material may lie.

The need for this new classification was created by the fact that explorations of the Bureau of Mines and Geological Survey during the war period were of such nature that they rarely yielded the information required by the engineering classification of "positive" (proved, in sight), "probable," and "possible," commonly used in the mining industry. The usual purpose of the Federal investi-

gations was to gain an approximation of the size and tenor of the deposit rather than, for example, to determine these features closely enough to form a basis for negotiation or to determine the geometry of the deposit in accurate enough detail so that a mining operation could be planned. A relatively small amount of information was needed to yield this approximation. Since on the usual project the ore was exposed mainly at drill-hole intercepts and not on any specified number of sides, it could hardly be called positive or probable under standard definitions; instead it became known as measured or indicated. In addition, it was desired to make some estimate of the total material potentially usable that might be present at any particular place or for any particular commodity, even though the quantity of such material had to be inferred from geologic knowledge only or from information on past production; material thus inferred to be present became known as inferred ore. The concept of inferred ore is especially valuable in appraising the kind of deposit that cannot very well be explored ahead of mining but that continues to produce year after year, though it rarely has much ore in sight.

The progression from measured to inferred ore represents a progression from estimates based largely on measurable data to those based largely on judgment; and the calculations under this classification thus represent the authors' personal appraisal of the quantity and quality of their information and the relative degree of proof of the existence of the reserves estimated. Moreover, inferred ore allows for new discoveries only to a limited degree. For some commodities, the reserves are estimated in terms of recoverable metal. Some authors found it desirable to use the terms "commercial," "marginal," "submarginal," and "potential" in conjunction with the other classification; either the meanings of these terms are self-evident from the context, or definitions are given.

Most chapters contain some appraisal of the national sufficiency of the reserves estimated. One method employed has been to divide the estimated reserves by the average annual rate of consumption. Thus it is said, for example, that the lead reserves are equivalent to 13 years of consumption, the zinc reserves to 26 years, and the iron-ore reserves to 40 years. These are not absolute values, of course, for (1) they assume that all the Nation's needs would be met from domestic production, (2) they make but small allowance for discovery, and (3) they make no allowance for the effect of depletion upon rate of production; but they do constitute a useful device for stating the adequacy of the reserves quantitatively and for allowing comparison between commodities. New ore, even beyond what has been inferred in making the estimates, will be found in the natural course of mining known deposits; and even though the rate of production declines with depletion, this increment will help sustain the rate. For this reason, the time at which serious decline in production may begin, due to exhaustion of present estimated reserves, is difficult to forecast.

As may be expected, the various commodity chapters show a wide range of achievement in presenting a comprehensive picture. The ideal mineral-resource study would include a comprehensive inventory of the material in the ground, a classification of this material as to its possible usability, a classification as to its recoverability, and opinion as to "life expectancy" and possible future rates of production. Not only must the inventory include an estimate of the material having the grade and metallurgical character that would permit its use under the economic and technologic conditions and the national policies prevailing at the time of inquiry; but it must also include materials of lower grade and less favorable properties, inasmuch as these may become the ores under future conditions, particularly during emergencies. By economic conditions is meant here largely cost, or rather the spread between cost and price; for, except in extraordinary circumstances, as in wartime control of labor and price, most economic conditions are reflected in this spread. Moreover, the reserves for each grade or kind of material should be classified as to whether they are measured, indicated, or inferred.

This estimate of the material in the ground is to provide the miner and metallurgist with the quantitative data necessary to enable them to judge the workability of the material under various conditions; consequently, the ideal study would show the full relationship between tonnage, metallurgical character, average grade, and a variety of cut-off grades. The cut-off grade is the lowest included; the average grade, perforce, is higher than the cut-off. The cut-off values considered might include not only grade but also thickness and dollar value, and possibly, such combinations of these three as might be suitable to the type of deposit and to the commodity. In other words, this part of the ideal study should be an estimate of total reserves in the ground in terms that

are most usable by some collaborator—present or future—whose duty it is or will be to consider the availability of the reserves under the conditions of the time. A mathematical calculation uninspired by such considerations could be worthless.

The ideal study would include an analysis and interpretation of this estimate of total reserves in the light of numerous variable and interrelated factors, including extraction methods and the effect of the method on mining (or pumping) recovery and dilution; milling (or refining) methods and requirements, and the dovetailing of these with mine or oil-field operation; the capacity to produce; and mine economics, including local costs, price, marketing, and nature and availability of labor. This analysis and interpretation would show the effect of these factors on both total and available reserves and on the amount of the usable element—metals or gasoline, for example—that might be recovered. For practical purposes, the over-all situation usually would be presented in terms of various price levels, for, as mentioned above, all factors are eventually reflected in price.

The ideal study would also include some opinion concerning the possibility of new discovery, taking into account possible improvements in methods of searching, as discussed in the chapter entitled "Search for New Mineral Supplies." It would include for each commodity a map of the United States—such as is included in this report for petroleum—showing the areas that are favorable for new discovery, those that are unfavorable, and those that are hopeless. It would include also careful consideration of the effect of substitutes; capacity to produce, in future as well as at present; and rate of production and degree of self-sufficiency, as influenced by capacity to produce, by depletion, and by new discovery.

The present effort fails, of course, to reach this ideal, for a number of reasons. One of the most important is a deficiency in data of all kinds; this is discussed in detail in the next chapter.

A second important reason is the magnitude of the task. There are many thousands of deposits, many geologic types, many industries, many factors to be reconciled in building up a national estimate from estimates of individual ore bodies, mines, and districts. Obviously, it is impossible to obtain complete data of the kind indicated for all the resources of the United States. The task would call for long-continued study by a corps of experts versed in the geologic, technologic, and economic aspects of each commodity. For example, the single phase of the subject covered by an appraisal of the extent to which new supplies are made available requires not only geologic appraisal of the amount remaining to be discovered but also appreciation of the increasing difficulties of making discovery and of the problems of development and processing. Assembling and training such a corps of experts is a slow and lengthy process.

The problem of presenting the studies on reserves in a form understandable and usable by laymen has been accompanied by its own difficulties.

Nevertheless, despite its limitations, this report is the most comprehensive treatment of the subject in existence. Unfortunately, even though changes in the mineral industries come but slowly, it will not be long before even the more complete parts of the report are out of date. The mineral-resource situation requires continuous attention, and estimates must be reviewed periodically. Succeeding efforts should improve materially upon this present initial attempt, for more and more data will become available and many of the difficulties encountered in the present study can be avoided through the experience gained.

DEFICIENCIES IN DATA ON MINERAL RESOURCES

By Samuel G. Lasky [5]

As noted in the preceding chapter, an ideal appraisal of the Nation's mineral resources would include an estimate of the tonnage and average grade of material known or inferred to be present in the ground, for all grades and kinds, pure or impure, usable or not at present; an estimate of the portion of such material that could be put to use under a variety of economic and technologic conditions, present and future; and the probable rate of future production. To make such an appraisal requires data of many kinds. Likewise there must

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be, for each commodity, a discriminating analysis of these data, and of the many factors involved in gathering and interpreting them. The most modest attempt at such analysis reveals that present information is deficient in many respects.

Reserves are variously calculated for individual ore bodies, for mines, for districts, and for the Nation as a whole. For each of these, the amount of information available and its nature and quality differ. For individual ore bodies, the information may be so complete and reliable that the problem is largely one of simple geometry and arithmetic, and the reserves can be calculated completely and with assurance. The information also may be complete for some operating mines that are nearing exhaustion and for the special kind of deposit that can be eliminated before mining; but usually such adequacy of information is lacking, both in quantity and quality, and is constantly changing as exploration and development proceed. In a broad way, these generalizations apply to the petroleum industry as well as to the mining industry.

As the appraiser passes from single mines, or mines of single ownership or similar geology, to districts in which more than one ownership or kind of deposit is involved, and thence to the Nation at large, the information available to him becomes progressively less complete and less reliable.

The national situation is particularly unsatisfactory in this respect. Industry has confined its search for ore to material that it could use within the spread of its plan of operation and, for some commodities, such as fluorspar, to areas tributary to market. The studies in economic geology by the Geological Survey have been influenced over the years by similar considerations. Thus, information on national resources is spotty, and for many commodities, such as those of which there had been little or no production, was virtually nonexistent until a few years ago. For example, the strategic minerals as a group had received less study than the more common ores, and much less was known about them. The geological and metallurgical studies and explorations by the Government and in some instances by industry since about 1938, on deposits and districts and kinds of material not then significant, yielded much new information; for some commodities, this new information is almost complete by present standards, but for many others information on a national basis is still lacking.

Mineral resources, which include coal, oil, and gas as well as the metals and other minerals, are natural products; therefore many of the problems concerning their appraisal are peculiarly geologic. Not all parts of the country contain valuable mineral deposits, and those parts that do contain only specific kinds. Moreover, not only are mineral deposits distributed erratically across the country, but they occur in a variety of geologic environments, depending upon their origin and the geologic events that have transpired since. Each kind of deposit has problems peculiar to itself. To appraise mineral resources on a national basis, there must be, for each kind, good knowledge of the geologic factors that control their general distribution, specific location, size, shape, attitude in space, richness, and purity. There must also be such information for each district and each deposit of each kind.

Much is known of the geologic factors that control ore bodies in the major producing districts; as a result, an appraisal of the reserves within the limited areas of these districts, so far as controlled by geologic knowledge, can be made with a fair degree of satisfaction. On the other hand, geologic knowledge in many other districts is still incomplete, and geologic knowledge of the factors that localize the districts themselves is both incomplete and speculative. Until the regional picture is better known and until at least the majority of mining districts and favorable areas have been studied with the purpose of appraisal in mind, it will be impossible to make comprehensive or accurate appraisals for the Nation as a whole, even for those commodities that have long been produced domestically, whose geology of occurrence is relatively well known.

As explained in the preceding chapter, mineral reserves are classified as measured, indicated, and inferred, the break-down for any commodity representing the appraiser's degree of assurance concerning the estimates given. Measured ore must be known with fair assurance, which can be assigned only to data contributed by those who have explored and developed the deposits. Except with reference to a few of the deposits tested by the Bureau of Mines, this means industry. For a number of understandable reasons, however, industry is not always willing to release such information to Federal agencies. Some private companies have done so, but in confidence. As a result, it has been possible to estimate measured reserves for only about a third of the commodities considered in this report, or, if estimated, to state them separately; much ore that would be

called measured or indicated by the operators must be called inferred in this report, because of incomplete information.

In many types of deposits, ore can be developed feasibly only from preexisting openings, so that development never extends far ahead of extraction. For this and various fiscal reasons, it is the usual practice to develop ore for only a short period ahead of requirements, as appropriate to the plan of operation of the individual companies or mines. Thus, although the management feels certain that it will continue to operate for many years to come, at no time have reserves been developed more than a few years ahead. This ore usually is developed with a degree of assurance that permits it to be called measured or indicated. The part that is likely to be mined in future but that has not yet been exposed must be classed as inferred. Such material constitutes a large proportion of the Nation's estimated reserves. A substantial part of the reserves estimated for the types of deposits that are little known is likewise inferred, not because of meager development but because of meager geologic information. Some deposits, such as those of mica and tantalum and certain gold deposits, are of such nature that the ore is mined out as rapidly as found; as a result, in this type virtually all the reserves must be classed as inferred.

The attempt to estimate the portion of the reserves that may be recovered and put to use—available reserves—reveals further and similar deficiencies in data. Since geologic factors have an important effect on how much of the material in the ground can be withdrawn—it is never possible to mine it all—the estimation of available reserves is both a technological and geologic problem, requiring a great amount of observation, sampling, and measuring as well as consideration of mining and milling technology. Human effort is too finite for the requisite amount of work to be done by a single group of men, even if opportunity existed; consequently the appraisal on a national basis must depend on information contributed by the industry. As with estimates of total reserves in the ground, the estimates of available reserves given herein are inaccurate or incomplete in proportion as such information has not been made available and as various operators have been in the habit of developing ore only for a limited period ahead.

Although in recent years there has been a growing tendency for a major part of production to be supplied by a few large deposits, an appreciable output of some commodities comes from a multitude of small deposits the exploitation of which is economically hazardous. For a few commodities all production is from such small deposits; since the ore in them is usually mined out as quickly as found, any estimate of the amount that may be produced must be based on past records, particularly as compared with past prices for the commodity, changing technology during the life of the deposit, and geology of the occurrence. This applies also to the kind of deposit in which the mechanics of mining makes development tantamount to extraction. For some commodities, or for some districts, such records are fairly complete, and the estimates based thereon are reliable in proportion to the experience of the estimator. For other commodities or districts, the records are scanty and the estimates proportionately weak. For still other commodities, such as flake graphite, strategic mica, and industrial diamonds, there is sufficient industrial background and therefore insufficient past record upon which to base any sort of estimate; opinion only can be given.

Similar deficiencies in data exist with respect to appraising the quantity of material that may be recovered under future, as well as present, economic and technologic conditions and to appraising future rates of production. The appraisal of the future for those deposits that are mined as quickly as found must be based upon records of past production, price, and technology; but, as noted above, such records are in part incomplete or lacking. In addition, the geologic knowledge required as a basis for analyzing the records is deficient for some commodities or districts.

The various deficiencies in data outlined above are due to a number of causes: (1) The practice of developing ore for a limited period ahead of requirements, (2) the industry's understandable desire to protect its interests, (3) lack of geologic data, and (4) lack of historical record both for those metals and minerals that have been supplied largely from abroad and for those for which there has been no past demand.

In conclusion, it can be noted that, for those resources and those commodities that have sustained continuing and profitable industries—such as petroleum, copper, lead and zinc, and iron ore—no public agency can hope to assemble the dependable comprehensive data needed to determine reserves in the measured category that are in the hands of private owners and operators, nor can it assemble the judgment, based on experience, necessary to appraise the future. This may

be true even for reserves in the indicated category. The estimates of "proved" reserves made for many years by the American Petroleum Institute, an agency representing private operators, constitute an example of the wealth of detailed information and experience in the hands of industry. On the other hand, no private agency has the background of regional geologic knowledge needed for a national estimate of inferred reserves, comparable to that held by the Government; nor can any private agency hope to acquire as comprehensive information for all aspects of appraisal as is had by the Government for the strategic metals and minerals. Because of this distribution of knowledge and specialized experience, the best efforts of both private and public agencies, acting partly in cooperation, must be available if the Government is to make a dependable appraisal of the Nation's mineral resources.

HISTORY OF DEVELOPMENT OF THE MINERAL INDUSTRY

By D. F. Hewett [6]

The story of the development of the mineral industries of America is a fascinating record of courage and adventure in search and discovery that began in the wilderness of the frontier and continues to modern times. The early needs of the first colonists included iron for utensils and tools and lead for bullets; and the list has grown until recent war years, when enormous quantities of more than 100 minerals were needed to maintain war consumption. Soon after the first colonists settled in New England and Virginia, they sought and found nearby sources of iron and lead that largely met their needs—but practically all of these were soon exhausted or abandoned in favor of better deposits farther from the coast. During the Revolution, the needs of the colonies in iron were met from numerous sources in Massachusetts, Rhode Islansd, Connecticut, New York, Pennsylvania, New Jersey, Maryland, Virginia, and the Carolinas; lead requirements were met from several sources in New York, Pennsylvania, and Virginia. A few of the iron deposits (northern New Jersey and Cornwall, Pa.) are still important sources of ore. A few copper deposits were discovered and opened by the Netherlanders as early as 1650, but much of the ore mined before the Revolution was shipped to the Netherlands and England for smelting and refining, because in colonial days the British discouraged the smelting, refining, and fabrication of metals in America.

There had been explorations west of the Allegheny Mountains, mostly military, before the Revolution; but during the next 60 years—from 1790 to 1850—there were numerous ambitious explorations, not merely to the Rocky Mountains but as far as the Pacific coast. These were, in part, private, such as those of the fur traders throughout the Rocky Mountains and Great Basin, and, in part, Federal, such as those of Lewis and Clark (1804–6), Pike (1805) and Fremont (1842–3–4), but they yielded little in the way of discoveries of valuable minerals. Meanwhile, however, in the Mississippi Valley and along the Atlantic seaboard, many of the sources of iron, lead, and copper that were to be important national sources, even after the Civil War, and the coal beds of Pennsylvania, Ohio, Indiana, Kentucky, Tennessee, and Virginia, were discovered and, to some extent, vigorously exploited. A brief list would include the iron deposits of northern New York (about 1800), New Jersey, eastern Pennsylvania, and Marquette, Mich. (1844); the limonite iron deposits of eastern Pennsylvania, Virginia, and Georgia (1840); the lead deposits of southeast Missouri and Wisconsin (discovered about 1725 and 1692, respectively); and the copper deposits of Ely, Vt. (1820). Ducktown, Tenn. (1843), and Keweenaw Peninsula, Mich. (1847).

From about 1850 onward, except for a slight recession during the Civil War, the general pattern of mineral discovery and development in the great region between the Mississippi River and the Pacific coast is similar to that of many frontier regions. As transportation methods were simple, primitive, and costly, search and discovery first were concerned with gold because its value is highest; then there tended to follow, in the order of value, silver, copper, lead, zinc, and iron. There is no such simple pattern for the other metals, fuels, and nonmetallic minerals. Among the ferrous alloy metals, manganese did not have much value until modern methods of making steel were developed about 1870, and the search for and use of chromium, tungsten, vanadium, and molybdenum only really began about 1900. Even though such metals as aluminum and magnesium were known

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early in the nineteenth century, the demand for great quantities of metals and therefore of the ores lagged until advances in technologic knowledge and methods of reduction permitted great reduction in the cost of production.

Sources of gold were found sporadically in Virginia, the Carolinas, and Georgia before 1850; and even though these were the only domestic sources until 1848, and although production was small, gold played an important role in the life of the young Nation. The discovery of placer gold in California in 1848 was fortuitous; but so much interest and feverish search followed the initial discovery that, within 5 years, most of the sources of placer gold, as well as lode districts that became important in California during the next 40 years, were discovered, and these discoveries profoundly affected the development of the entire West. Even though the discovery of gold stimulated transcontinental travel over several routes to the west coast, little in the way of mineral resources was discovered in this region before the Comstock lode was found in Nevada in 1859 by miners who had forsaken the California gold fields. In spite of the Civil War, that discovery initiated a campaign of search and prospecting throughout the entire intermountain region. Attention was first directed toward gold in placer deposits; and between 1860 and 1870, many such deposits were found in Montana, Idaho, Wyoming, Colorado, Utah, Nevada, and Arizona. The production of some of these placer deposits was impressive, but a much more important result of the prospecting was discovery of the copper-, lead-, silver-, and zinc-bearing lodes that were generally the source of the gold. In many of these districts, the value of the output of other metals has greatly exceeded that of the gold from the placers, and some are still among the principal national sources of these metals. Among the mining districts that were first sources of placer gold and later became major national sources of the base metals may be mentioned Butte, Mont. (copper, silver, zinc); Coeur d'Alene, Idaho (lead, silver, zinc); Leadville, Colo. (lead, silver, zinc); and Bingham, Utah (copper, lead).

Other results of the discovery of gold in California were, first, the surveys for transcontinental railroad routes between 1850 and 1860, which included a search for mineral deposits; and, next, the construction of the four major railroads to the Pacific coast—the Union Pacific (completed in 1869), the Southern Pacific (completed in 1881), the Santa Fe (completed in 1882), and the Northern Pacific (completed in 1883). There had been modest production from numerous base-metal districts throughout the Intermountain States before the railroads were completed; but with their completion many small smelters were built, and production increased rapidly. Also, cheaper transportation further stimulated prospecting throughout the entire region.

With only a few exceptions, discovery and development of the placer-gold and base-metal mining districts preceded settlements based on agriculture. Noteworthy exceptions were the agricultural settlements of northwest Oregon (1846–50) and of central Oregon (about 1843 and earlier), and the Mormon settlements in Utah that began in 1847.

The decline in the price of silver about 1892 brought stagnation to mining in most of the metal districts of the West. The discovery of the Cripple Creek gold district, Colorado, in 1891 was the first of several important discoveries (Tonopah, silver, 1900; Goldfield, gold, 1903; and others in Nevada, Utah, Colorado, and Arizona), which renewed popular interest in western metal mining. Meanwhile, advances in mining and milling techniques led to the development of many of the present important sources of copper which, though known for many years, had maintained modest production from sporadic high-grade deposits—Bingham Canyon, Utah (1902); Ely, Nev. (1905); Miami, Inspiration, and Ajo, Ariz.; Santa Rita, N. Mex. (1910); and others.

Thus, with the exception of iron, fuels, and nonmetal mining, the organization of the mineral industries of the West by 1910 took the pattern we now see. A few districts of modest importance have been discovered since 1910, and many new ore bodies have been found in known districts, but among the 40 districts that now yield nearly all of our gold, silver, copper, lead, and zinc, none have been discovered since 1910. The San Manuel copper district, near Tucson, Ariz., discovered in 1944, which promises to be of major importance, will not come into production for several years.

The systematic search for mineral deposits in the Lake Superior region began with the development of the copper deposits of Keweenaw Point and the discovery of iron deposits in the Marquette range, Michigan, about 1844. This

search was rewarded by the discovery of other iron ranges—Menominee, about 1850; Gogebic, about 1848; Vermillion, about 1880; and Cuyuna, about 1903. Of these, the development of the Mesabi range has had the most important and far-reaching effects on the distribution and size of the manufacturing industries of the eastern United States that are based upon steel. In 1942, when the production of iron ore reached the astounding total of 126,500,000 tons, the output of the Mesabi range alone was almost 60 percent of this amount. Of the total production of iron ore from the Lake Superior ranges—about 2,000,000,000 tons since 1854—approximately 65 percent or 1,300,000,000 tons has come from mines on the Mesabi. These ores are smelted at centers along the lower Lake ports on Michigan and Erie and near Pittsburgh, and the resulting iron and steel are the basis of the most important concentration of industry in the world, that which extends from Illinois through Indiana and Ohio to Pennsylvania.

The early explorations in the West led to the discovery of many deposits of iron ore, but the smelting of iron was confined to modest sporadic efforts until an iron and steel plant was constructed at Pueblo, Colo., in 1881. It was based upon several sources of iron ore in Colorado and New Mexico but principally on those near Hartville (Sunrise), Wyo. The next development was the construction of an iron furnace near Provo, Utah, in 1924 based upon iron ore from the Iron Springs district and coal from Sunnyside, Utah. Several plants for making steel from local scrap were erected along the Pacific coast before 1920, but it was not until 1942 that an integrated iron furnace and steel plant was erected in the intermountain region (Geneva, Utah). Like the plant at Provo, it drew ore from the Iron Springs district. At the same time, the iron and steel plant at Fontana, Calif., was built, based upon ore from an iron deposit near Kelso, Calif.

Unlike discoveries of the metals, coal was not discovered first along the Atlantic seaboard but in the interior of the present State of Illinois. This discovery was made about the middle of the seventeenth century by French missionaries. Small mines were opened in central Virginia early in the eighteenth century and in Ohio a little later. In spite of its widespread distribution in Pennsylvania, coal was not reported there before the latter part of that century and was not developed until after 1800. Virginia fields were the principal source of coal consumed along the seaboard until early in the nineteenth century. Most of the early explorations west of the Allegheny Mountains as far as the Rocky Mountains noted the occurrence of coal near the travel routes. Beginning some years before the Civil War and continuing with increased activity following that war, both State and Federal agencies made maps showing the distribution of coal fields, so that by 1900 the outlines of all major coal fields had been fairly well established.

The history of the development of the petroleum resources of the Nation is a fascinating record that began with fortuitous discovery in many regions and has been sustained recently by the intensive application of geology and geophysics to the search for and recovery of petroleum from the earth. Even though progress was slow before 1900, in recent years no other mineral industry has so thoroughly sought for and applied scientific principles in the search for and recovery of a product; it can fairly be stated that in no country in the world has scientific inquiry been used so widely, so wisely, and with better results in the search for petroleum as in the United States. The Drake well, drilled in western Pennsylvania in 1859, was not the first well to encounter petroleum; some years earlier, persons in several parts of the country drilled for brine from which to recover salt and found petroleum also. When the Drake well was drilled, however, there was a shortage of whale oil and of "coal oil" distilled from coal, which was met by the new "rock" oil. Within the next few years, many wells were drilled throughout western Pennsylvania, New York, Ohio, West Virginia, Kentucky, Tennessee, and even as far away as Colorado. Production reached its zenith first in Pennsylvania in 1891; in Ohio, 1896; in West Virginia, 1900; and in Indiana, 1904. These peaks were followed by many years of declining production; but in each, development of new techniques in recovery and deeper drilling led to rejuvenation of many fields and reversal in the trend of production, although in the Eastern States, except Illinois, recent peaks have not been as high as the early ones.

Among the principal present sources of petroleum—Oklahoma, Kansas, Texas, and California—discoveries were made before 1890, but production lagged until about 1900; these States then quickly assumed the leadership in national production—Oklahoma from 1915 to 1918 and in 1927, California from 1903 to 1914, and from 1923 to 1926, and Texas continuously since 1928. The national output for

1944 reached the astonishing figure of 1,700,000,000 barrels, the highest yet recorded.

Most of the nonmetallic minerals used in industry have low unit value, much lower than those of the common metals, so that their development always awaits the rise of local industries, increase in nearby population, or great improvement in transportation facilities. Salt, lime, clays, and stone were used to some extent before 1871, but the birth of the portland-cement industry in that year and the subsequent rapid expansion of manufacturing greatly extended the markets for nonmetallic minerals. The development of portland cement created an increasing demand for cement raw materials, and the use of concrete structures has greatly increased the market for sand, gravel, and crushed stone. The growth of manufacturing provided a growing market for many nonmetallic minerals in the metallurgical and process industries. By 1880 the value of production reached $56,000,000, and in recent years it has exceeded a billion dollars, a twentyfold increase compared with only an elevenfold increase in the value of metals produced in the United States.

Other significant developments in the growth of the nonmetallic mineral industries include the beginning of mining of phosphate rock for fertilizer in the Southern Seaboard States (South Carolina, 1867, Florida, 1888; and Tennessee, 1893); the invention of the Frasch process for recovering native sulfur from the deposits along the Gulf coast toward the close of the nineteenth century; the development of the world's largest source of borate minerals in California, beginning about 1880; and the growth of the potash industry. Until about 1890, domestic needs for potash were met from wood ashes; from then on, for about 30 years, the country depended almost completely upon imports of potassium salts from Europe. The discovery of potash in brines from oil wells in west Texas in 1913, systematic drilling in west Texas and New Mexico from 1926 to 1931, and the exploitation of the deposits thus discovered, beginning in 1931, together with further development of the Searles Lake deposits, Calif., have led since 1940 to complete national self-sufficiency, which is now assured for many years.

In a broad way, the development of Alaskan mineral resources has followed the pattern of many other frontier regions. As in the western part of the United States, most of the early explorations were made by those in search of furs; and, after a few discoveries of gold in placers, subsequent intensive search yielded numerous gold placer and lode deposits. The first recorded discoveries of placer gold in the far Northwest were made in British Columbia (Stikine River, 1863) and Yukon territory (Yukon River, 1867); but in Alaska the first discoveries were at Windham Bay and Sumdum Bay on the mainland between Juneau and Petersburg, and these yielded the first gold production in 1870, 3 years after Alaska was purchased from Russia. Soon there followed discoveries of gold in lodes near Sitka (1877) and Juneau (mainland, 1880; Douglas Island, 1881), and the latter district has been an important source to the present day.

The discovery in 1896 of gold placers along the Klondike River, a tributary of the Yukon River in Canada, had much the same effect upon the search for gold and other minerals in Alaska as that in California in 1848 had upon the region west of the Rocky Mountains. Within 5 years at least 50,000 prospectors and adventurers flocked to the upper tributaries of the Yukon River, both in Canada and Alaska, and to the more easily accessible coastal regions of Alaska as far north as Seward Peninsula. They were rewarded by many discoveries, but the outstanding were the beach placers of Seward Peninsula (Nome, 1898) and the river placers of Fairbanks (1901), which are still the most important sources of gold in Alaska. During the interval 1895–1910, most of the sources of minerals in Alaska that have become important, or that promise to be important when transportation facilities are improved or economic conditions are more favorable, were discovered.

Numerous copper deposits have been found in the drainage basin of the Copper River in the Prince William Sound region and on the islands of southeastern Alaska. The outstanding deposit, the Bonanza on the south slope of the Wrangell Mountains, was discovered in 1900; but development and shipments lagged until the Copper River Railroad, 200 miles long, was completed in 1910. It had an impressive record of production before it was abandoned in 1938.

The only other metal besides gold and copper that Alaska has produced in sizable quantities is platinum from the platinum-bearing placers of Goodnews Bay in the western part of Kuskokwim region, southwestern Alaska. Placers on Seward Peninsula and at some other places and lode deposits in southeastern Alaska have also yielded a small production of some of the platinum-group metals.

Even though the existence of coal in several parts of Alaska was known and some was mined for local use as early as 1888, development has been spotty and has been directly controlled by the development of local markets. The bituminous field of the Matanuska Valley was explored as early as 1902, but there was little development until construction of the Alaska Railroad began in 1915. When that railroad was extended to Fairbanks, another field containing lignite—the Nenana—was developed to supply the needs for power of the region north of the Alaska Range. Another bituminous field, the Bering River in northern Alaska, was slightly developed but has been inactive for many years. Other fields in northwestern Alaska are virtually untouched.

Petroleum has been developed at only one place in Alaska, the Katalla field near the Bering River coal field, where seeps first attracted attention in 1898. This field has yielded about 150,000 barrels of oil but has been inactive since 1933.

No complete statistical record of mineral production in the United States exists for the period preceding 1880, in which year the output was valued at $367,463,000. By 1944 the value had increased to $8,452,000,000, the highest on record up to that time and an increase of 2,200 percent over 1880. Figure 5, which shows

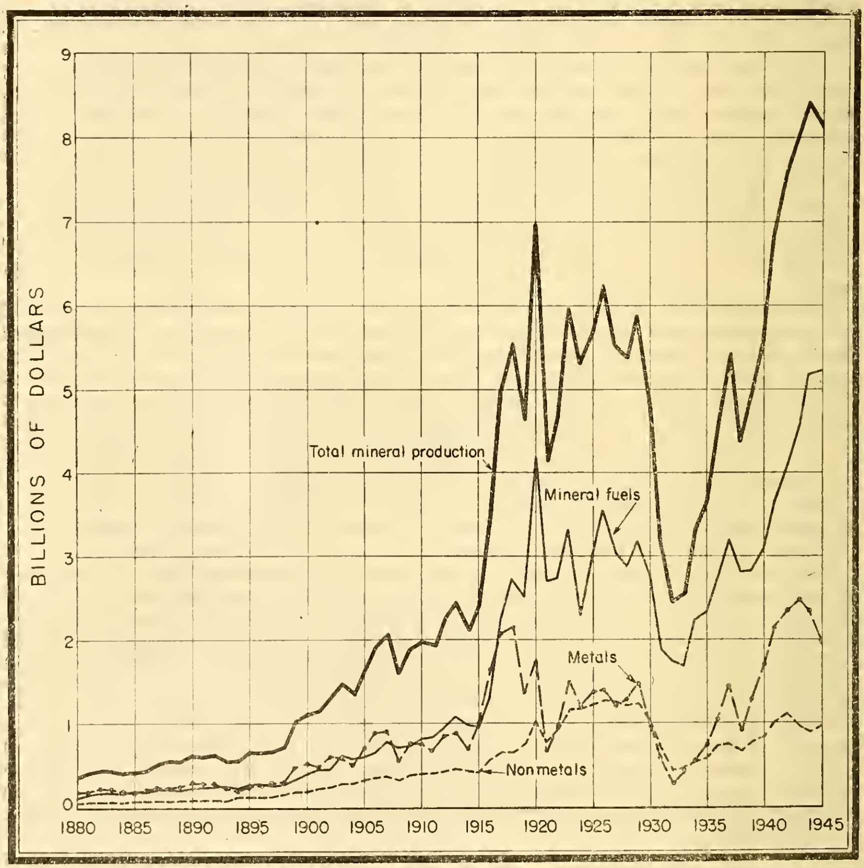

FIGURE 5.—Trends in value of mineral production in the United States, 1880–1945.

the trends in the value of mineral production from 1880 to 1945, illustrates the outstanding importance of the mineral fuels in this advance. In 1880 they represented only 33 percent of the total value, whereas in 1944 coal and petroleum, with its related products, accounted for 61 percent of the total. This gain was due entirely to the phenomenal growth in the liquid and gaseous fuel industries. The value of coal production was 26 percent of the total both in 1880 and 1944, but the value of petroleum and its related products rose from 7 percent to 35

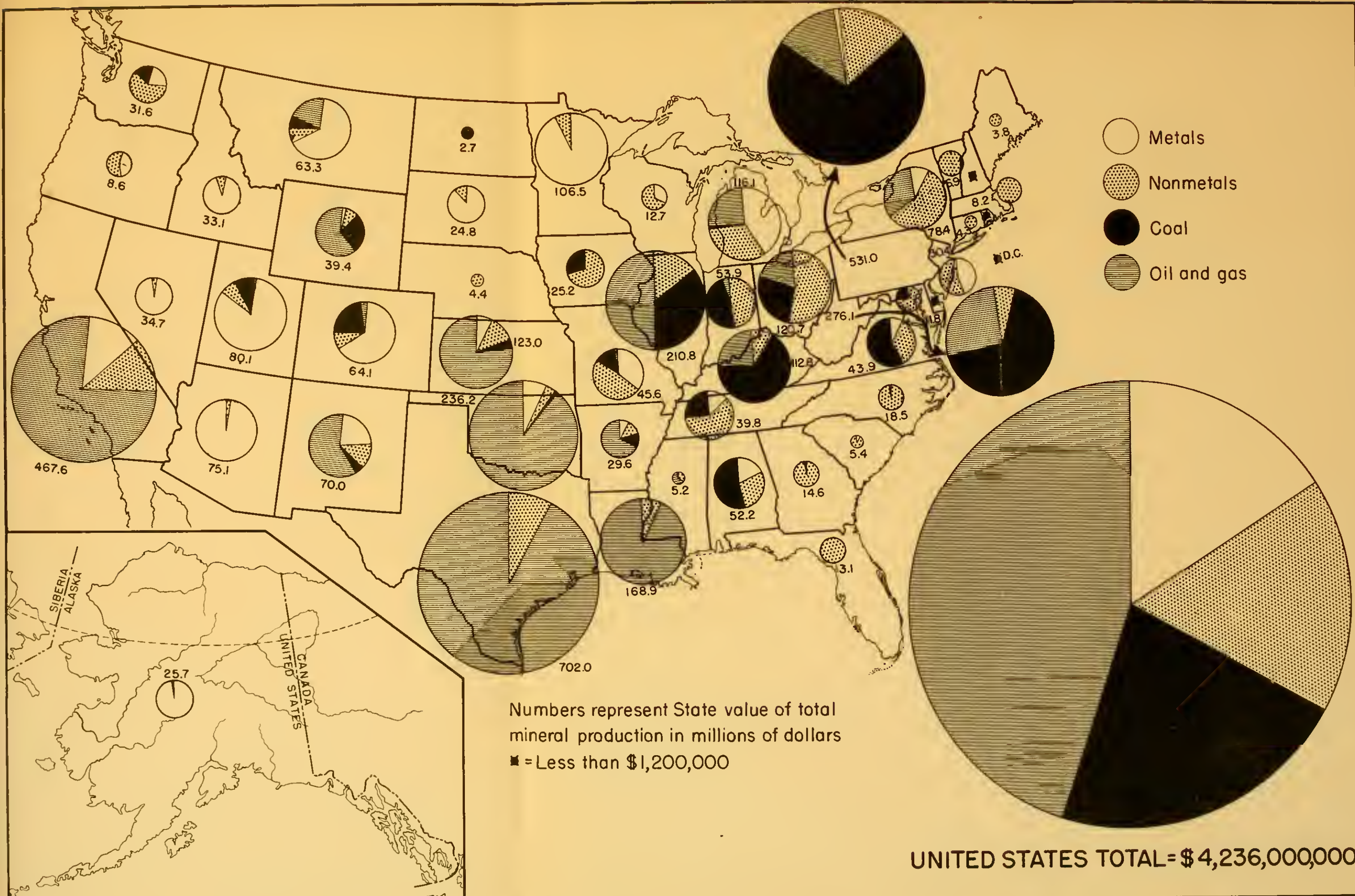

CHART I—Value of mineral production in 1939, by States.

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percent of the total. In the same period, the proportion of total value contributed by metals declined from 51 percent to 28 and that by nonmetals from 16 percent to 11.

Chart I shows the distribution of the value of mineral production in 1939, by States. Texas, which ranks first in production of the liquid and gaseous fuels, also ranks first among the States in total mineral output. Pennsylvania ranks second and West Virginia fourth, chiefly because of their outstanding coal industries. Petroleum and allied products account largely for California's position as third largest producer.

TRENDS IN TECHNOLOGY AND OUTLOOK FOR IMPROVEMENT IN MINERAL POSITION

Search for New Mineral Supplies

By Samuel G. Lasky [7]

INTRODUCTION

The chapter in this report entitled "Summary" specifies 13 metals and minerals in which the United States is deficient to some degree but in which there is good expectation of improving the Nation's mineral position through discovery of new deposits. This chapter discusses the technical methods of search upon which the discovery must depend.

It can be said with some certainty that much new ore will be found in the natural course of operation in established mines and districts, through extending known ore bodies and finding new ones, and even in the discovery of new mines; but viewed in light of long-term needs, the Nation's main hope of replenishing and augmenting its reserves lies in the discovery and development of new districts. Most ore exposed at the surface in readily accessible regions has already been found. The search must now focus on areas known to be mineralized but not hitherto greatly productive, on other areas that are geologically favorable but in which the deposits are concealed by younger rocks, and on regions hard to reach. It is primarily a geologic job, in which, however, every field of effort that can be of assistance must be employed. As known deposits become exhausted, the search requires more and more extensive, more precise, and more realistic geologic studies; it requires painstaking geologic effort, shrewd appraisal, and high scientific skill. Although the economic geologist has long recognized and used the related sciences of geophysics, particularly in oil discovery, he is now giving closer scrutinity to its possibilities and limitations. Moreover, he is turning to a second related science—geochemistry—and to the mining engineer for improvements in the physical methods of exploration.

GEOLOGIC METHODS

Fundamentally, any search for new mineral deposits should be based upon a sound geologic concept of origin—where the material came from, the way in which it reached its present location, and its manner of accumulation therein. In applying this principle, however, it has to be recognized that the source of the material usually must be inferred; moreover, migration and accumulation resolve themselves into what are known as habits—pattern of distribution, rock associations, and a variety of usual geologic features. Thus, regardless of concepts of origin, the geologist must know the habits of the material he is seeking. Mineral deposits have regional habits, district habits, and local habits; and, in the final analysis, the geologist must determine these habits with enough reliability to form the basis of prophecy. The basic principle is that, inasmuch as minerals originate, migrate, and accumulate in accordance with the laws of physics and chemistry, similar sets of conditions tend to yield similar results.

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These principles refer alike to the search for fuels, metals, and nonmetals; and in future paragraphs reference to ore bodies, mines, or districts applies in general to pools and fields as well.

Mineral deposits, of whatever kind, exist because of the co-occurrence in space of many natural features. If any one of a number of features should be missing, deposits of significant size will not have been formed; like a royal flush, only one "card" need be missing for the entire "hand" to be worthless. The required features, however, differ with respect to districts, mines, individual ore bodies, and extensions of ore bodies. The geologic habits of ore bodies in the usual producing district are fairly well known; and, in them, analogy of pattern is an established and effective means of searching for extensions of known ore bodies and for new ore bodies. The habits of the larger entity known as a mine are much less well known; and the habits of districts are even less well known. It is as yet a mystery to geologists why one region or district should contain a rich accumulation of material whereas another district close by, in which the geologic conditions seem similar, should contain but little.

As stated in the introduction to this chapter, it is in the search for new districts that the major hope of discovery lies—in the very field of endeavor in which geologic knowledge is least. This field, therefore, needs the greatest development of applied geology. Fortunately, particular kinds or types of deposits and particular kinds of materials tend to occur in particular environments. Consequently, when any commodity is considered, the expert promptly knows something of its habits and the problems of its discovery. The chapter on Petroleum in this report contains a map showing not only the present productive fields in the United States but also (1) the areas from which future commercial production is possible; (2) those from which it is improbable; and (3) those from which it is impossible. An initial step in the search for new supplies of any commodity should be an attempt to prepare such a map. Although, for most commodities, present information is far from adequate, for a few—such as chrome, vanadium, potash, and phosphate—a map could be prepared with fair assurance at present. The preparation of such maps serves a double purpose; not only does it form the basis of search for and appraisal of resources, but it also forces a conscious reappraisement of the state of geologic knowledge.

The science of geology has been used widely in the search for mineral deposits for only about 50 years. Various scientific theories concerning the origin, migration, and accumulation of minerals have been developed, some of which coalesced into basic concepts. Insofar as they were based on facts and intelligently used and inasmuch as there were relatively many deposits to be found, these theories and concepts were effective instruments of discovery; in proportion as they were successful, the theories came to be considered as fact and the concepts as dogma. The petroleum geologist was the first to question the adequacy of accepted theories and concepts. Anticlines—upward folds in the rocks in which oil may be trapped under an impermeable layer—have been sought for many years as favorable structures on which to drill for oil, but it is now known that oil is associated also with faults, salt domes, and other features. In relatively recent years it has been discovered that some oil reservoirs, of the type known as stratigraphic traps, are in discontinuous layers of porous rock—a type that has, to date, yielded one-fourth to one-third of domestic production. In addition, oil exploration has been extended to greater and greater depths, partly because of improvements in drilling technique but also because of changes in geologic thought; it is now being extended under the continental shelf. In a general way, as each concept of the influence of various geologic features has developed and has been applied, it has yielded a new crop of discoveries. It would be foolhardy to say that new ideas and methods of the future will be less fruitful.

In the field of metals and nonmetals, a few geologists began to question accepted theories and methods of attack as much as 15 or 20 years ago, and during the past 5 years this iconoclastic attitude has become pronounced. This has been partly a natural development, stimulated by the need for discovery that faces the Nation as a result of the great wartime drain on its resources; in part, it was prompted because the intensified search for materials during the war both revealed a number of weaknesses in accepted geologic thought and forced the development of a technique and philosophy specifically designed to aid in the search for ore. Present-day thought is based on and is proceeding along the following lines and principles:

1. Field activities are of three kinds, which may be called regional, district, and local studies. The area covered by the regional studies is variable, depending on the particular study, but it is large. It may include an entire geologic province and be spread over several States; or it may be a mineralized region, including several mining districts. The purpose is multifold: To determine the geographic distribution of favorable areas, both throughout the Nation and in a relatively local sense; to indicate areas worthy of examination and study in greater detail; to determine any features that may characterize the productive districts as compared with nonproductive ones; and to furnish the general framework of information upon which district studies must be based and interpreted. The regional study may cover all aspects of the geology of a single commodity, or it may be confined to a single geologic problem.

District studies are somewhat detailed investigations of smaller areas, usually an average mining district. The purpose is to learn, if possible, the factors that have localized the ore bodies and on the basis of that information to indicate places where undiscovered bodies may lie. Local studies generally cover individual mines and are made in great detail; they are the kind that normally constitute the day-to-day jobs of company staffs and consulting geologists.

2. The purposes of the regional studies, as listed above, are based on two convictions, which are worthy of being listed as constituting a separate principle. One is that a broad geologic and geographic knowledge of ore deposits is necessary for full and accurate interpretation of more local information and for accurate appraisal of the mineral possibilities of an area. The second is that, if careful geologic studies are made of regions that contain both productive and relatively unproductive mineralized areas, features would be found, in addition to those already known by geologists, that tend to characterize the producing districts and that would thus constitute useful guides for search; at least, information would be obtained and generalizations developed that would go a long way toward restricting, geologically and geographically, the areas in which undiscovered deposits should be sought and which would be applicable on local, regional, and semicontinental scales.

3. A geologic study of a mineralized or otherwise favorable region made for some purpose other than search or appraisal is not a satisfactory basis for the search for new deposits. As a corollary to this, it should be said that the study should be made by one who is a specialist in mining geology and who, in addition, is convinced of the likelihood of success.

4. Very little is known, in the strict sense of the word, about the formation of mineral deposits; most is inferred or assumed. As a result, the validity of accepted theories and concepts, and evidence of all kinds, must be carefully scrutinized in deciding whether an area is favorable or, once that is decided, in determining where to explore and to what extent. An increasing number of geologists are asking themselves, in such circumstances, not only the question: "Should ore be here?" but also "Could ore be here?"

Geological studies cannot be made without making geologic maps. In addition, geologic maps constitute an integral part of any but the most haphazard search for ore. They achieve their greatest usefulness at two stages—during exploration, when they must form the basis for locating exploration openings and when there must be an endless series of them, and in the appraisal that follows, when the size, shape, attitude in space, and distribution of grade of ore bodies, as well as the geologic features surrounding them, must be shown. They require a high degree of ingenuity on the part of the geologist, for no two deposits are exactly alike—the problems of some may best be shown in plan; for others they may best be shown by cross sections, projections, isometric drawings, or specially designated diagrams. Some maps are permanently useful, whereas others may have a life of only a few days, while a specific piece of exploration is underway or a specific problem is being investigated.

The mechanics of making maps is fairly well established, except for individual differences in technique. It changes mainly with opportunity for access to the area to be mapped. Until recently, access could be had only on foot. Progress was slow; and accuracy was sacrified for sake of completion. Motor vehicles, and more recently the airplane, have made difficult regions more accessible, and in doing so have speeded the mapping process and permitted an increased accuracy that is greatly needed. The reconnaissance map of today is equivalent to the detailed map of yesterday; a similar generalization should be possible concerning the map of tomorrow compared to the map of today.

The motor vehicle and airplane have enhanced the possibility of discovery also in that the regions difficult of access—deserts, rugged mountains, forests, and

swamps—offer some of the greatest promise. The airplane, in particular, makes it possible to see gross features that may escape an observer on the ground—or at least to see them quicker—and thus is a special aid in spotting areas for detailed study.

One other feature of the application of geology to the search for new mineral supplies remains to be mentioned. The major advances in the science of ore deposits have been made as a corollary to the search for scientific fact, not as a result of the practical search for ore. The commercial geologist waited for the research geologist to make these academic advances and to bring them to him for practical application. This is changing; research geologists are beginning to orient their efforts directly toward the search for new deposits, and commercial geologists are doing more and more research. Partly, this is because of the great economic need, but also it is due to recognition of two facts: (1) That the search for ore requires high scientific skill and penetrating scientific inquiry; and (2) that there exists what may be called a "happy" circle, in which the search for ore leads to discovery of scientific truths, while the scientific discoveries in turn open new possibilties for economic discovery.

GEOPHYSICAL AND GEOCHEMICAL METHODS

Geophysics is the use of physical science for investigating earth problems. Correspondingly, geochemistry is the use of chemical science for such purpose. Just as physics and chemistry are closely related, so are geophysics and geochemistry related, and it is difficult to separate them in any discussion.

When the science of geophysics is mentioned in connection with the search for mineral deposits, what is commonly meant are the usual magnetic, electrical, gravimetric, or seismic methods whereby are measured the magnetic or electrical properties of the rocks, their relative density, or their ability to transmit sound or earthquake waves. Radioactivity methods have recently come in for consideration. The attempt to apply these methods in the search for petroleum and metalliferous deposits was begun almost as soon as geophysical theories and techniques were developed.

As with geology, the science of geophysics is used more widely and successfully in the search for oil than for any other mineral commodity. No comprehensive program of search is planned or carried out in the petroleum industry without systematic and correlated geologic and geophysical studies. Its application has been developed to a high degree, and research on new methods, techniques of application, and fields of application is continuously in progress; there is no question of its continued and probably increased usefulness, even though possibly accompanied by increased cost.

Geophysical studies never indicate the presence of oil, either directly or indirectly, but only yield information that must be interpreted geologically. As regards metalliferous deposits, on the contrary, there is some opportunity for direct discovery. Past efforts at direct discovery have been successful at some places, unsuccessful at others; and we may expect the established methods to be increasingly successful in this respect as time goes on, particularly if the several methods are used with discriminating regard to their special fields of usefulness. Established magnetic methods have direct application in the discovery of naturally magnetic materials, such as ores of iron, titanium, and chrome, and of nonmagnetic materials where associated with magnetic ones, as in the successful exploration of the deep-lying, gold-bearing conglomerates of South Africa. Established gravity methods are usable in the search for iron ore and chromite, and, in the opinion of some geophysicists, for deposits of lead and zinc under specially favorable geologic and topographic conditions, as in the Mississippi Valley. Electrical methods are useful in prospecting for sulfide ore bodies, which are better electrical conductors than the enclosing rock and which by weathering generate feeble electric currents in the earth.

In addition to the established methods, however, there is an expanding field for research, not only along the lines of established methods but also along new lines; in seeking ore by direct discovery and in seeking it indirectly through correlating the geophysical with the geologic studies; in searching out deposits in known mineralized areas; and in searching for deposits covered by younger rocks. The search for unknown districts or extensions of known districts under cover is an especially attractive field and the work being done on taking observations from the air is an especially attractive component thereof. Some geophysicists believe that gravimetric and induced electromagnetic, as well as naturally magnetic fields, can be measured from the air. The least hope in this connection is

that concealed mineralized areas might be located thus. It might even be possible in such places to differentiate between the various zones that characterize many districts, in which each zone contains its special kind of deposit.

Some ore bodies are known to be close enough to the surface to be bathed by waters percolating downward and give off heat, because of chemical reaction between the ore and water. Here and there geologists are making comparative studies of geothermal gradients—measuring the temperature of the rocks below the surface and the rate at which it increases with depth and comparing this rate with the usual ore in unmineralized areas—with the hope of discovering concealed ore bodies through detecting such heat. This kind of study can be extended to the search for even deeper deposits. There must be a chemical reaction of some sort, however mild, between an ore body and the ground water that traverses it, and therefore there must be either consumption or liberation of heat. Perhaps the distortion of the geothermal gradient that results is great enough to be measured.

The successful use of ultraviolet light during the war in the search for tungsten suggests another example of research along new lines, because many minerals beside the tungsten mineral scheelite fluoresce under ultraviolet light. These include some of the zinc minerals that are commonly, though in small amount, present in the outcrops of certain zinc districts; ultraviolet light might help to determine the places where zinc ores had been originally present and thus, indirectly, help to find new ore.

Since geophysics indicates only local abnormalities in the earth's physical properties and since such anomalies may exist for many reasons besides the presence of a valuable mineral deposit, geophysics has greater indirect value in the search for ore than in direct discovery. It can be used to obtain valuable geologic data that might otherwise evade the searcher; it can be used to test—verify, support, or discredit—geologic interpretations that could be tested otherwise only by costly exploration; it can precede the geologic studies and thus help guide them, as well as follow and help in interpreting them. Research can be conducted on a number of subjects that, though seemingly academic, have a pertinent bearing in the search for ore in some circumstances.

Application of the related science of geochemistry to the search for mineral deposits is relatively new. Geochemical methods are, consequently, in an early stage of development, and opportunities for research and application correspondingly rich. Because this application of the science is new, the attempt to develop and apply it soundly requires careful analysis and definition, both in regard to possible scope of application and to objective.

Many agencies, public and private, are now carrying on research in geochemistry. Collaboration between them is desirable, particularly to define and classify the phases in the life history of a mineral deposit or mineralized area in which geochemical processes have played a part and in the study and appraisal of which geochemistry would now be useful. Geochemistry, for example, would have no bearing on the size and shape of the masses of igneous rock with which some mining districts and ore deposits are associated or on the formation of the openings in rocks that later become receptacles for ore where those openings are due to physical processes; it does have possible application in the processes in which there was passage of solutions. It is applicable also in the study of some deposits that were formed contemporaneously with the rocks that enclose them, as, for example, in the study of the phosphate-vanadium deposits of Wyoming and Idaho. Sound research will require a full and clear appreciation of the differences, as they control the possible application of geochemistry, among deposits of the fuels, metals, and nonmetals, between deposits formed with the enclosing rocks and those in which the valuable minerals were emplaced at some later date, between kinds of deposits in each group, and between eastern and western deposits.

The possible applications of geochemistry may well differ according to whether the search for new deposits covers unknown districts, groups of ore bodies composing the usual mine, or single ore bodies or extensions thereof. If concealed mineralized areas of district magnitude are being searched for, the geologist would be looking, perhaps, for the results of alteration of rock on a grand scale, such as the great haloes involving cubic miles of rock around the porphyry copper deposits. If he is searching for mines or ore bodies, the geologist would be looking, among other things, for changes along major ore-carrying channelways.

A brief list of some of the specific questions that face both the researcher in geochemistry and the geologist who would apply the science in the search

for new deposits indicates its possible wide value. Are chemical elements dispersed, or are changes effected in the alteration of rock on a district scale different from those in the more immediate vicinity of ore bodies? Some base-metal deposits contain traces of such elements as gallium and indium, or cobalt in western zinc deposits; are such elements present only in the ore minerals, or are they more widespread? When ground waters pass through ore bodies, either shallow or deep, do they pick up and retain significant elements in measurable quantity? Is the clay (fault gouge) along veins in the vicinity of ore different from the clay elsewhere in a vein system; and are there important differences between the clay minerals that form the fault gouge and those in the altered rock near ore? Are the constituents of an ore body or oil pool reflected in the soil or vegetation above it, and to what extent and in what way? This list could be greatly lengthened even now, were it desirable to do so; it will be multiplied when the geologic basis for geochemical research and application is fully analyzed and defined.

As with geophysics, the greatest application of geochemistry is as a corollary and support to the geologic studies, rather than in direct discovery.

PHYSICAL EXPLORATION

In the search for mineral deposits, a hole of some sort must be made sooner or later to obtain visual evidence that ore is present. Although originally such physical exploration was solely to expose ore, at present it is used also to obtain geological information as an aid in geologic study and to test the opinions and conclusions of the geologist in the many steps leading to economic appraisal. It may range from the digging of a shallow pit or the cleaning of an outcrop to elaborate underground excavation.

In its broader aspects, physical exploration is divided into exploration of the surface and exploration below it. The present surface was once, before being exposed by erosion, below some previous surface, anywhere from a fraction of an inch to many thousands of feet. It constitutes a random cross section of the area or deposit and, if properly interpreted, can tell much about conditions below. In exploration below the surface, diamond drilling (despite its well-recognized draw-backs) is commonly used wherever possible in preference to other methods, because of its speed, relative cheapness, flexibility, and the ease with which the records of the work—the drill cores—can be stored for future reference. Consequently, most present-day efforts to improve exploration methods are directed toward improvements in diamond drilling, even though other drilling tools and methods are used from time to time where specially appropriate. Some of these other tools and methods are the churn drill, the bucket drill (adapted from California cesspool digger), the truck-mounted "seismograph" drill, and power augers.

The improvements in diamond drilling have as their objectives better samples, greater speed, reduced cost, certainty as to the location of a hole drilled, and certainty as to reaching the target.

As has been aptly said, the samples extracted and the information gained, not the holes, are the reason for drilling. Improved drill bits and cutting mediums, and improved machines that give the operator better control over drill-core recovery, tend to achieve this purpose and to increase speed and reduce cost as well.

One of the handicaps in the search for ore by diamond drilling has been that usually the exact position of the drill hole in depth—and consequently the location of the samples from it—is not known. Except under special circumstances, drill holes tend to deviate from their initial course; and the hole when completed may occupy a position that bears little relation to, and that cannot be inferred from, the initial course. The intense exploration program carried on from 1939 to 1944 revived a lagging interest in the United States in drill-hole surveying and an appreciation of the need for it; as a result, necessary improvements in surveying methods can be expected.

A second handicap, both in searching for ore and in doing so at a reasonable cost, is the difficulty of reaching a specified target with a drill hole because of this tendency of the hole to "wander." Good results can be achieved by shrewd allowance for deviation of the hole from its initial course; but beyond a limited depth, which may vary with circumstances, it becomes increasingly difficult to reach a specified objective. Directional drilling—drilling a hole in any direction and at any angle desired—has become standard practice in some oil-field drilling, and research aimed at similar practice in diamond drilling for ores should be

profitable. Efforts at directional diamond drilling have been made from time to time, and some success has been claimed, yet the fact remains that it is not yet standard practice. The small diameter of the usual diamond-drill hole presents difficulties in the matter of inserting a mechanism to control the direction of the hole, but such mechanical difficulties are no greater than have been overcome in other problems.

In some circumstances, it is the usual practice to drill a number of holes from a single position of the drill, fanning them in different directions to reach different targets. In such practice the initial part of most of the holes is lost, because each hole traverses much the same path as its predecessor until it gets far enough on its divergent course to penetrate new ground. There will be a valuable saving in cost and time when directional diamond drilling becomes sufficiently practicable for the initial part of the first hole to be used for succeeding holes, by deviating them from the first at some deep and appropriate point.

Efficient and successful drilling is handicapped also by difficulties in cementing caving ground. Whereas any kind of cement seems to work in some districts, nothing seems to work well in others, because the cement will not set, will not adhere to the rock, or will not support the walls. Determining the cause of such difficulties and developing cementing materials and methods to overcome them are real needs and have begun to receive serious attention from some exploration geologists.

CONCLUSIONS

The discussions above about geologic, geophysical, geochemical, and exploration methods in the search for new mineral supplies make no pretense of having exhausted the subject but indicate, nevertheless, that there is opportunity for progress in every branch of search. Some of the opportunities are now being investigated and pursued by both public and private groups, but nowhere is there a coordinated, well-rounded program based on national needs.

Three alternatives seem to face the United States in regard to replenishing and augmenting its reserves by new discovery: It can search for new mineral supplies by traditional methods; it can continue along the course being followed at present, in which some research and modification are haphazardly combined with traditional methods; or it can establish a comprehensive, integrated, long-term program of research and exploration. Under the first alternative, serious decline in the Nation's over-all self-sufficiency is inevitable—for some commodities at a date not far distant. The second alternative doubtless will lead to discoveries that otherwise would not be made, but the gamble is great. The third alternative offers the greatest chance for discovering any major deposits not yet found; to what extent success may be achieved only the attempt itself can tell, but, properly integrated, the skills of the geologist, geophysicist, geochemist, and mining engineer should prove effective instruments of discovery.

MINERAL TECHNOLOGY

Solid Fuels

By Arno C. Fieldner[8]

INTRODUCTION

Recent developments in fuels forecast the use of coal on a scale and for purposes never before seriously considered, even in its heyday as the Nation's preponderant source of fuel and energy. From 461 million net tons in 1940, the production of bituminous coal and lignite increased to 620 million tons in 1944. In the same period, the production of anthracite increased from 51 to 64 million tons. This large increase in demand was occasioned principally by the growth of war industries. Part of it also was caused by the substitution of coal for oil, which was not available in sufficient amount to supply the unprecedented need for liquid fuels. Much of this recovery of former markets for coal may continue after the war if the rate of discovery of new petroleum fields does not increase. Unless the supply of petroleum is augmented by the discovery of more and larger new pools of oil than have been found during recent years, fuel oil for industrial purposes will necessarily be replaced by coal. Likewise, natural gas, which now supplies much of the continental United States, will need to be

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supplemented by gas from coal, and probably in the not-distant future synthetic liquid fuels from coal will be required to supplant a declining supply of oil. These shifts will require important progress in the technology of coal preparation and utilization, especially with reference to the lower grades of bituminous coal and all grades of subbituminous coal and lignite.

The reserves of high-grade coking coals of the United States have been depleted by the war. Some of the coal now being used for making metallurgical coke contains more sulfur and ash-forming material that is allowable in normal specifications. Technologic progress must be made in coal preparation whereby the sulfur and ash of the more-abundant low-grade coals can be reduced to the desired limits for blast-furnace coke.

The extraordinary requirements of steel for conducting mechanized warfare led to a maximum capacity of production of 72 million tons of byproduct coke per year during the recent war. The peacetime production in 1940 was 54 million tons. Some years will lapse before the normal expansion of the country's population will absorb this difference of 18 million tons. However, this extra capacity can be absorbed to advantage in supplying the necessary demand for smokeless residential fuel that should follow the resumption of urban smoke-abatement activities.

These activities, if reinforced by municipal ordinances compelling the use of smokeless fuel-burning equipment or smokeless fuels, such as was instituted in St. Louis, Mo.,[9] are bound to increase not only the domestic market for high-temperature coke as now manufactured for industrial use, but also for low-temperature coke, provided that relatively low cost processes can be developed for manufacturing this fuel. Another important aid to the commercial success of processing coal for the production of solid smokeless fuel is the recovery of commercially valuable byproducts. The outlook in this direction is improving owing to the decline in reserves of petroleum and the growing use of plastics made from byproducts of the carbonization of coal. Such demands, together with supplementary natural gas and petroleum resources, will require much technologic progress in the mining, preparation, and processing of coal and lignite in the period following the war. A brief résumé of these trends will be given in the discussion that follows.

MINING

The greatest technologic progress in America relating to coal has been made in mining. Hard pressed by the loss of markets to competitive fuels—oil and natural gas—in the period following World War I, the coal industry gave special attention to lowering the cost of production by mechanizing mining operations. Marvelous advances were made in the development of highly efficient machines for cutting, loading, and transporting coal in the mine. The total percentage of bituminous coal and lignite mechanically loaded underground increased rapidly from 12 percent in 1935 to 27 percent in 1938 and to 49 percent in 1943.[10] On account of mechanization, the average tonnage of bituminous coal mined per man per day increased from 4 tons in 1920 to 5.06 tons in 1930 and to 5.38 in 1943 at the peak of the war effort. The maximum amount for underground mining in 1942 was 13.4 tons per man. The general increase of underground mechanical mining operations, as well as of large-scale mechanical strip-mining, has made it possible for the coal industry to meet successfully the increased demands of the war program, even though nearly 15 percent of the bituminous-coal miners left the mines because of the draft or to accept higher-paid jobs in war plants.

Increase of strip-mining was most helpful in maintaining a high level of coal production in the face of declining manpower. The percentage of strip-mined bituminous coal and lignite increased from 8.7 in 1938 to 13.5 in 1943. The average tons of coal mined per man per day in stripping operations in 1942 was 13.1, and the maximum was 62.5. These trends are likely to continue and present some important problems for solution. Public opinion will require more attention to the preservation and restoration of the surface soil where coal is strip-mined in agricultural areas. For the same reasons, underground min-

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[9] Ordinance 41804, amending art. 36, ch. 34, of the Revised Code, City of St. Louis, 1936, * * * relating to the regulation of air pollution and the emission of smoke, * * * and regulating the use of fuels and equipment, * * * approved April 8, 1940.

[10] Fieldner, Arno C., Recent Developments in Fuel Supply and Demand: Bureau of Mines Inf. Circ. 7261, 1943, p. 11.

ing methods must be modified in the more populous regions so that the surface is not disturbed by subsidence or the countryside polluted by the smoke and sulfurous fumes from burning refuse banks.

The greatest of all mining problems is increasing the recovery of coal. Far too large a percentage of good coal is left in the mines. Even as rich a country as the United States cannot afford to continue leaving 20 to more than 30 percent of good coal in worked-out mines. Such coal is irretrievably lost.

Much of it should be saved by improved mining technique, and comprehensive research for developing the technological improvement of coal recovery should be conducted by industry and Government. This cooperation is justified by the national interest in fuel conservation. The exhaustion of the thicker, more minable coal seams will require the best efforts of both Government and industry in devising improved techniques for mining thin and deep beds of coal.

PREPARATION

The growth of mechanization in coal mining, the increase in strip mining, and the gradual exhaustion of the better grades of coal have made it more important to remove impurities by washing. About 15 percent of the coal produced in 1935 was washed or air-cleaned. This proportion increased to 18 percent in 1938, to 22 percent in 1940, and to 25 percent in 1943.

There should be a marked increase in the percentage of coal cleaned in future, not only because of the more insistent public demand for coal of uniform quality, but also because mechanical mining and strip mining introduce more impurities into the coal, which must be removed in a washing plant.

Much research should be conducted on improvement of cleaning methods, especially the finer sizes of coal and the dewatering of these sizes.

UTILIZATION

Combustion

About 13 percent of the bituminous coal consumed in the United States is processed for the production of gas and coke. The remainder is burned directly in the production of heat or power. Therefore, combustion and appliances for burning coal conveniently and efficiently are of prime importance in the utilization of coal. Naturally, this predominant field of use has not been neglected. The average consumption of coal per kilowatt-hour of electrical energy in public-utility power stations has declined from 7.05 pounds in 1899 to 1.34 pounds in 1941. The most efficient modern stations are producing 1 kilowatt-hour from 0.8 pound of coal. This efficiency is near the maximum possible and does not offer much further possibility of improvement. However, public-utility power plants account for only 12 percent of the consumption of bituminous coal. Most coal is burned with much lower efficiency, and its use is much less convenient than that of liquid and gaseous fuels.

Industrial stokers and powdered-coal combustion have reached an advanced stage of development. In recent years, coal producers, in cooperation with manufacturers of appliances, have made considerable progress in developing improved automatic stokers that have much of the convenience of gas or oil burners at a lower cost for fuel. The sales of mechanical stokers for residential use increased from 7,000 in 1932 to 76,000 in 1936 and to 179,000 in 1941.[11]

Attention also has been given to the improvement of simple room heaters for burning bituminous coal without the production of smoke, and it is predicted that several new stoves of this type will be on the market in the near future.

The treatment of coal with oil, to allay dust and to prevent difficulty in unloading cars, due to freezing, had become so popular that prohibiting the use of oil for this purpose in 1942 created a real hardship for the coal industry. Solutions of hygroscopic salts combined with corrosion inhibitors continue to be available and are used for antidust treatment.

Present research on the use of coal in modern power stations is directed toward preventing slag corrosion of metal heating surfaces and refractories; reduction in the amount of ash and sulfur gases discharged into the atmosphere; and other improvements in operating equipment that will permit the use of lower-grade fuels.

Railroads are the largest industrial group of coal consumers, using about 22 percent of the coal consumed. Whether the Diesel or other oil-burning locomo-

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[11] U. S. Department of Commerce, Bureau of the Census, Factory Sales of Mechanical Stokers: Current Statistical Service, February 3, 1943, p. 2.

tives will continue to displace coal, depends largely on the trend of relative costs of oil and coal and on technological improvements.

A serious diminution in petroleum supplies will result in the use of much more coal for transportation. If petroleum continues to meet the demand, important improvements must be made in utilization of coal in locomotives. Sherman[12] has called attention to the possibilities of increasing efficiency by using higher boiler pressures or condensing operation both of which offer difficult, but not impossible, problems for solution.

A gas-turbine locomotive is on trial in Switzerland. Research is in progress in this country, and improvements in alloys for high-temperature use and in methods of ash removal probably will permit the development of a pulverized-coal-fired gas turbine that eventually will supplant oil-burning Diesel engines.

Carbonization

The expansion of the steel industry during the war required a corresponding increase in the production of metallurgical coke. Production increased from 57 million tons of coke in 1940 to 74 million tons in 1944. Ten percent of the production was beehive coke. Despite the loss of gas and byproducts in beehive coking, their use is justified for temporary use because of their low investment cost.

The excess capacity of byproduct-coke ovens, above that required for the postwar steel industry, may find good use in making smokeless fuel for residential heating. Such fuel will not require the best grades of coking coal. These are none too plentiful, and they should be reserved as far as possible for the production of metallurgical coke.

Having in mind the decrease in reserves of high-grade coking coals, the Bureau of Mines[13] and others have made studies of the gas-, coke-, and byproduct-making properties of American coals and of blends of coals with a view to producing metallurgical cokes from coals that by themselves do not make blast-furnace cokes of suitable chemical and physical properties. Considerable research is needed on the removal of sulfur from high-sulfur coals or on the development of methods of treatment in the coking process that will volatilize the sulfur or put it in such form in the coke that it will not appear in blast furnace pig iron.

The popular notion of large financial returns from the byproducts of the coking or gasification of coal is exaggerated. Thirty percent of the coal tar produced in 1942 was burned as fuel. The average return on all coal tar sold was 5.4 cents per gallon. The amount of tar and light oils for the production of dyes, explosives, and a host of other chemical commodities is a relatively small part of the total production; consequently, the price of crude tar depends largely on its value as fuel.

Some of the constituents of light oil and tar have special value. These are benzol for synthetic rubber, aviation gasoline, plastics, and explosives; toluol and xylol for explosives and solvents; and phenols, cresols, and lighter tar acids for plastics. These materials should continue to be in demand; however, some can be and are being made from petroleum. Most of the toluol used for the production of TNT in the recent war was made from petroleum.

Considerable new development in the production of chemicals from coal, petroleum, and natural gas is probable, but the total amount of these mineral fuels used for this purpose will be small compared with their use as fuels.

Complete gasification

The complete gasification of coal as practiced by the larger public-utility manufactured-gas companies is a two-step process. The coal is coked in retorts or ovens, and the coke is converted to water gas, which is enriched with oil cracked in the water-gas machines. The gas sent out is a mixture of coke-oven gas and carbureted water gas having a calorific value of 500 to 550 B. t. u. per cubic foot. Bituminous coal or anthracite also has been used in water-gas generators.

As natural-gas and petroleum resources decline, it will be necessary to make gas from coal by complete gasification, without the necessity of finding a market for excess coke or of raising the calorific value of the gas by carburetion with oil.

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[12] Sherman, Ralph A., Fuels of the Future: Battelle Memorial Inst., mimeographed paper, 1943, pp. 22–23.

[13] Fieldner, A. C., and Davis, J. D., Gas-, Coke-, and Byproducts-Making Properties of American Coals and Their Determination: Bureau of Mines Monograph 5, 1934, 164 pp.

German and British investigations have shown that it is possible, with the aid of oxygen and continuous pressure generation (about 20 atmospheres), to produce a gas of 400 to 500 B. t. u. per cubic foot heating value. Practical catalytic methods for methanating water gas also have good possibilities for replacing oil enrichment where economic constituents favor such changes.

Such processes are needed especially for the complete gasification of lignite and subbituminous coal. More than half of the coal reserves of the United States consist of these low-rank noncoking coals. No satisfactory equipment for their complete gasification has been developed in this country. Work should be done on this problem because the coals are appropriate raw materials for the production of hydrogen and carbon monoxide from which liquid fuel is synthesized by the Fischer-Tropsch process.

Liquefaction

The direct liquefaction of coal and lignite by hydrogenation or by synthetic conversion of water gas from solid fuels is the most recent addition to the family of processes for the indirect utilization of coal.[14] More than half of the liquid fuel used by Germany in the war probably was made in the numerous synthetic-liquid fuel plants that were built during the last two decades. Imperial Chemical Industries in Great Britain also operates a 3,500-barrel-a-day plant, and Japan has operated several commercial-scale pilot plants.

Experimentation on the hydrogenation and liquefaction of American coals has shown that, in general, coals ranging in rank from lignite to high-volatile bituminous, inclusive, are suitable for hydrogeneration.[15]

In 1944, the Congress, concerned by the decline in discovery of new oil fields in the United States, passed Public Law 290 authorizing the Secretary of the Interior, acting through the Bureau of Mines, to design, construct, and operate demonstration plants for the production of synthetic-liquid fuels from coal, oil shales, agricultural and forestry products, and other substances. For the fiscal year ended June 30, 1945, an appropriation of $5,000,000 was made to start the program. This was followed by appropriations of $7,000,000 for 1946 and $7,250,000 for 1947. Research laboratories and pilot plants have been constructed and equipped. The work is in full progress, and the designs of demonstration plants are nearing completion. Industry also is exploring the possibilities of producing synthetic-liquid fuels.

These programs provide the type of assurance against lack of vital supplies that is needed for the national defense. In future this Nation must not be as dependent on importation of foreign oil in time of war as with respect to rubber at the outbreak of the recent war. Since mineral fuels are the principal source of the energy on which modern civilization depends, the United States should conserve them and encourage research on the more difficult phases of preparation and utilization of these irreplaceable resources.

PETROLEUM

By C. L. Moore[16] and R. M. Gooding[17]

Additions to petroleum reserves in the United States are reported by the American Petroleum Institute in two classifications. One classification is the additions to reserves resulting from the discovery of new fields through exploration. The second classification covers additions to reserves resulting from extensions to and revisions of previously discovered fields. This latter classification is directly dependent upon additional subsurface information on discovered deposits and upon drilling and production practices which increase the proportion of oil recovered from such deposits. Both of these desirable objectives are directly related to advances made in drilling and production technology through engineering research.

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[14] Fieldner, A. C., Statement in hearings on synthetic liquid fuels before a subcommittee of the Committee on Public Lands and Surveys, U. S. Senate, 78th Cong., 1st sess., S. 1243, August 1943, pp. 168–178.

[15] Fieldner, A. C., Storch, H. H., and Hirst, L. L., Bureau of Mines Research on the Hydrogenation and Liquefaction of Coal; Am. Inst. Min. and Met. Eng., Tech. Pub. 1750, 1944; Bureau of Mines Tech. Paper 666, 1944, 69 pp.

[16] Petroleum engineer, Petroleum and Natural Gas Division, Bureau of Mines.

[17] Petroleum chemist, Petroleum and Natural Gas Division, Bureau of Mines.

Recent studies [18] have shown that 80 percent of the additions to reserves during the 10 years from 1937 to 1946 were due to extensions and revisions of previously discovered fields. The remaining 20 percent of the additions to reserves during this period were credited to discoveries of new fields.

This study also reveals the fact that nearly 60 percent of the present remaining proved reserves are due to gains in reserves made before 1932. Gains in reserves for any given period are defined as the total additions to reserves during that priod minus the withdrawals from reserves during the period.

For the 20-year period 1925–44, additions to petroleum reserves in the United States, through extensions and revisions to fields discovered before 1925, amounted to 4,848,000,000 barrels.[19] This is 91 percent more than the 5,321,000,000 barrels of remaining proved reserves estimated by the American Petroleum Institute as of December 31, 1924.[20] These additions to reserves were made because of increased subsurface knowledge and the application of improved recovery methods resulting from engineering research.

In New York, Pennsylvania, and West Virginia, which include most of the Appalachian oil-producing region, results from engineering research were four times greater, on a percentage basis, than the average for the country as a whole. In other words, the increase in this Appalachian region was 362 percent as compared with 91 percent for the United States. Practically all of this 362-percent increase in additions to reserves from 1925 to 1944, from fields discovered before 1925, in these three eastern oil-producing States, is due to the application of improved recovery methods through engineering research. In this instance, the development of secondary recovery through water flooding is the dominant source of this increased recovery.

It is significant to note that, although the American Petroleum Institute Committee of Eleven discusses the possibilities of water flooding in its 1925 report previously cited,[21] its estimated proved reserves for New York, Pennsylvania, and West Virginia were only 150,000,000 barrels. Actual additions to reserves, from the fields in this area discovered prior to 1925, exceeded this estimate by 543,000,000 barrels, or 362 percent during the following 20 years ending in 1944.[22] Clearly the potentialities for increased recovery through technical progress existed, but vigorous and far-sighted action by the industry was necessary to convert them into realities.

A similar situation exists today for the country as a whole. The potentialities exist for tremendously increasing oil recovery from known deposits through applied research. The oil industry has but crossed the threshold of increased recovery from known deposits through advancing technology. The challenge of continued withdrawals demands a vigorous response by the industry and all organizations engaged in oil-recovery research. A greatly expanded fundamental research program is an immediate and imperative need, if the results of such research are to be applied on a large enough scale to meet the challenge of depletion of petroleum deposits in this country.

PETROLEUM REFINING

Historically, ever since the installation of the first thermal cracking unit over 30 years ago, most technological advances in petroleum refining have yielded products of improved quality and increased quantity. Such advances mean a more efficient utilization of our crude-oil reserves, since products of an enhanced economic worth are obtained from crude-oil fractions of less value. This trend in petroleum-refining technology will continue.

As an example, the newer catalytic cracking processes are replacing some of the older thermal cracking methods to produce unleaded motor gasoline of 77-octane number (ASTM motor method) from the same crude-oil material that yields gasoline of 66-octane number by thermal cracking. Fourteen such catalytic cracking units were built during the war for productive aviation-gasoline material, and many will be converted to motor-fuel production. Ten additional such units are now under construction, the largest having a charging-

[18] Bureau of Mines bulletin in preparation.
[19] See footnote 18.
[20] Committee of Eleven, American Petroleum Supply and Demand: A Report to the Board of Directors of the American Petroleum Institute: McGraw-Hill Book Co., 1925.
[21] See footnote 20.
[22] See footnote 18.

stock capacity of 25,000 barrels a day. Solvent-extraction plants for the manufacture of lubricating oil are replacing and augmenting the older acid-treating systems and allow production of the best-quality oils from mixed-base crude oils as well as from paraffin-base. Demands for lubricating oils are expected to increase an approximate 20 percent in the next 5 years over a 1946 production of 45,000,000 barrels.

Today the petroleum industry is producing enormous volumes of specialized products, not only for motor and aviation fuel use but also for use by those industries requiring organic chemicals that can be produced from petroleum. The largest organic synthesis ever completed was the peak production by petroleum refiners of 135,000 barrels per day of commercial iso-octane for aviation-gasoline blending during the war. Less than 0.2 percent of the total weight of crude oil produced in the United States in 1945 was required for the production from petroleum of 390,000 tons of butadiene for synthetic rubber during that year. The total production of chemical raw materials from petroleum and natural gas in 1945 was 1,650,000 tons, an increase of 100 percent over 1943, but still less than 1 percent of the total crude oil produced.

It is logical to assume that the present trend in petroleum refining toward the production of the higher-priced products will continue. An anticipated increase in demand for all petroleum products in the next 5 to 10 years means that this increased demand will make the production of specialized products still more profitable to the refiner. Necessarily the supply of lower-priced petroleum fuels may suffer from this competition, with possible relinquishing of these markets to other materials, such as coal or shale oil.

Further extension of the Nation's supplies of petroleum fuels undoubtedly will come from development in the synthetic production of fuels from natural gas, coal, oil shale, or other materials, and results from present operation and research in this field will be studied carefully by all refiners. The demand for fuels and products predominantly hydrocarbon in composition may outstrip the supplies available from our domestic crude-oil production at some future date, but this demand can be met by the production of such materials from the estimated 160 trillion cubic feet of natural gas, the 92,000,000,000 barrels of shale oil, or the 3 trillion tons of coal available in this country.

That the refiners are aware of the ever-increasing value of technical progress in petroleum research is evident in plans by many companies for research staffs double their present size, in spite of a present scarcity of technical personnel and equipment.

MINERALS OTHER THAN FUELS

Mining

By McHenry Mosier [23]

During the past several decades, the trend of ming has been toward exploitation of leaner ores and ores at greater depths. The present outlook is for an expansion of this trend because of the dwindling reserves of higher-grade ore and the exhaustion of shallow deposits.

As lower operating costs have been realized through improved technology, wider application of scientific management, better-educated workers, larger production units, and the continued rise in America's industrial efficiency, former subcommercial material has become ore that can be extracted with a margin of profit comparable to that from yesterday's higher-grade ores. The important consideration is the cost of the metal or finished product.

Mechanization of ore loading and transportation is an important contribution to this trend. Hand shoveling is becoming obsolete. In underground mines, the size of scrapers or slushers has increased so that electric power for them is almost universal. Efficiencies in this work are being raised by remote control of electric motors, which permits the operator a clear and unobstructed view of the work. Mechanical loaders powered with air motors for loading are expanding their use. Larger, electrically operated loaders continue to operate in open stopes, as well as in tunnels where high-speed construction is at a premium. The mobility of mechanical loaders mounted on crawler-type tractors is increasing the speed of some underground operations.

[23] Chief, College Park Division, Mining Branch, Bureau of Mines.

In shaft sinking, mechanical mucking rigs with orange-peel or clamshell buckets have increased the rate of advance beyond that attained by hand shoveling. Belt conveyors and shaking conveyors are proving practicable under specialized conditions. Rubber-tired trucks operated by storage batteries have solved some underground transportation problems in old mines, where relaying of steel rails for track haulage would have been prohibitive. Some Diesel haulage equipment is being used underground.

The principles developed for Diesel locomotives are applicable to Diesel trucks. Ample ventilation is the solution for successful operation of Diesel equipment underground. In open pits, truck haulage and belt conveyors in several places have reduced costs and prolonged the life of mines by the extraction of ore unrecoverable by former methods.

Improvements in blast-hole drilling have been continuous. The use of diamond drills for this purpose is increasing, particularly in stopes at mines where long holes have reduced the amount of stope development required under former practices. Precast or impregnated diamond-drill bits, in which small stones are mechanically set at the factory in an appropriate matrix, as well as machines that are lighter weight and more efficient, have helped dimond drills to compete successfully with percussion drills in this field.

In driving development headings, diamond drills are making it possible to improve drill rounds. For example, the burnt-cut has been modified by diamond drilling a large-diameter hole toward which the round breaks, thus saving drilling, explosives, and time.

Percussion drilling is being improved through better design of the machine drill and the increased use of detachable bits. Although high-carbon steel is a good material for fabricating these bits, vanadium and other alloy steels offer promise of improvement in rock drilling. Bits of entirely new designs are being developed for more rapid drilling but are not yet available for commercial distribution.

The use of jumbos or drill carriages is increasing. The design and construction of jumbos are being required for special applications. In large open stopes, mobile drill carriages are being mounted on crawler-type tractors. Hydraulic drill jibs designed for high-speed tunnel driving are also proving effective in drilling on slopes. Drill carriages and jibs contribute to greater speed and safety in drilling operations.

The adaptation of shaped charges of plastic explosives to mining is in the experimental stage, However, progress has been made in the use of shaped charges of explosives for breaking boulders, loosening rock in hung-up chutes, breaking hard layers of rock in the bottom of churn-drill holes, and producing blast holes in rock to shallow depths.

Fusion piercing, or burning holes in rock with a torch, offers some promise of commercial application to open-cuts for large-diameter holes in hard rock.

Standardization of mine operations that are repeated many times, such as loading cars, drilling rounds, setting timbers, laying track, and many others, is being adopted at a large number of mines. This decreases costs by increasing the output per man and by reducing the number of personal injuries of the workmen. That safety is efficiency is becoming more widely appreciated, because the correct way of doing a job is the safe way. Some companies, after an analysis of their operations, have adopted improved standard practices, descriptions of which have been reduced to writing for the instruction of personnel.

In underground mines, increasing depths are bringing burdensome problems in drainage, ventilation, and support of mine openings. Higher lifts are being attained for single-stage pumps, made possible by better materials of construction and improved technique. Air cooling is being included in mine-ventilating systems to lower rock temperatures in advance of ore extraction. In some districts, openings are maintained in critical areas at depths below 3,000 feet by preventing concentrations of rock pressures that are great enough to cause rock failure. Fairly accurate forecasting of rock bursts, based on research by the Bureau of Mines in several mining districts, has been demonstrated by microseismic equipment through the amplification of subaudible vibrations arising from incipient rock failure. Mine operations may be controlled in future through knowledge of rock stresses in critical areas. Rock bursts not only can be predicted but also, in some instances, may be averted through dispersal, or transfer of dangerous stresses to neutral areas by an appropriate sequence in development or stoping. However, further research is needed in the United States and other countries on this deep-mine problem.

With increased scale of operations where conditions permit expansion of output, larger equipment in many instances becomes permissible and proves

more efficient. These large-scale plants require a correspondingly greater amount of capital investment and working capital. During the recent war, the Government facilitated greater production of minerals by financing additions to plants, thus assuming the risk arising from the uncertainty of metal markets.

Treatment

By O. C. Ralston[24] and W. H. Waggaman[25]

Introduction

Mineral deposits are not resources until they can be made to serve some useful purpose. Therefore, the character and quantities of material included under the heading "Mineral reserves" are subject to profound change as knowledge is increased through fundamental research and experimentation on both a laboratory and pilot-plant scale. There is ample proof that mineral deposits considered of little or no value by our ancestors became sources of immense wealth to the generations that followed. Much are now regarded as marginal or submarginal, therefore, will doubtless be brought into the economic picture through new and improved metallurgical processes.

Some outstanding technical developments

Innumerable instances could be cited to show where technical developments have provided necessities and luxuries when supplies of certain raw materials appeared to be running low. Heavier and more powerful equipment, ingenious devices, and improved technique have rendered available large, deep-seated deposits of oil, sulfur, phosphate rock, salt, and potash previously regarded as impractical to exploit; improvements in ore-dressing methods, such as tabling, flotation, and magnetic and electrostatic separation, have made possible the handling of low-grade ores and tailings that would not have been considered 30 to 40 years ago; the establishment of magnesium as a structural metal and the development of alloys having greater strength, hardness, and resistance to corrosion have already brought about profound economic changes; the fixation of atmospheric nitrogen, the hydrogenation of coal and oil, and the manufacture of numerous synthetic compounds have banished the fear of shortages of many natural raw materials long regarded as essential.

The effect of technical developments on America's mineral resources is well-illustrated by phosphate rock. In 1915 the commercial reserves of Florida phosphate were placed at 214,500,000 tons. In 1924, after 19,000 000 tons had been mined and marketed, the reserves were estimated at 294,000,000 tons. Again in 1937, after the introduction of flotation and furnace methods of treating phosphate deposits of lowest grade, the estimated reserves were 552,000,000 tons. Then in 1938, when all new and improved methods of mining and processing were considered, the reserves were estimated at 13,000,000,000 tons or nearly 60 times greater than they were 23 years before.

The development of the aluminum industry is another outstanding example of what metallurgical research can do toward converting long-neglected mineral deposits into valuable national resources. Less than 60 years ago metallic aluminum was almost a curiosity, and bauxite deposits were regarded as of little importance. Our total production of aluminum in 1884 was only 150 pounds valued at $1.41 per pound; and the possibilities that this metal would ever become an important structural material seemed very remote. Today this Nation's aluminum-producing capacity is over 900,000 tons per year and the price has dropped to 15 cents per pond. Bauxite deposits are now eagerly sought and represent highly prized mineral reserves.

Technical advance under emergency conditions

Many if not most of our technical advances have been made under the spur of necessity. This applies particularly to the mineral industry, where, as long as available high-grade raw materials can be mined cheaply and require simple processing steps, little interest is evidenced in developing methods for utilizing lean ores and waste products. But the time is fast approaching when this country must depend on ores that were formerly regarded as marginal or submarginal to help supply its industrial needs.

Mineral deposits are not replaceable, and many of the better grades of easily accessible ores that can be readily processed have been seriously depleted.

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The heavy demand due to 4 years of war has put an additional strain on the remaining reserves, and it is becoming increasingly evident that if America is to maintain its leadership among the world's great nations it must, among other things, employ an improved technology adapted to the raw materials available. This will necessitate fundamental and applied research on the lower-grade mineral deposits, improved methods of benefication, and changes in existing metallurgical and chemical practices.

So-called "rare" metals not so rare

As far as we know, certain chemical elements are not only relatively scarce, but sparsely distributed throughout the world; others have been termed "rare" partly because their extraction and isolation have presented formidable difficulties and since their known properties did not appear particularly desirable, there was little incentive to produce them. Among what were once considered rare metals that have definitely found important places in industry are chromium, tungsten, and vanadium, but many others offer promising possibilities.

To cite a few—boron, barium, calcium, titanium, and zirconium, four of which are more plentiful than copper, lead, or zinc, are being isolated and their properties studied. Some of the domestic ores of these elements are very lean, others are relatively high grade and very plentiful, although the processes now known for isolating the metals have been tedious and costly. Methods of concentrating lean ores are being constantly improved, and better and cheaper means of reducing the concentrates to metallic form are being developed. Interesting and valuable facts regarding these elements are being learned that make their production economically desirable, even at a high cost. In view of the inherent possibilities of such materials, a diversified program of research in the field of pure metals is being carried forward.

Electrolytic manganese, for instance, acts like an entirely different metal from that prepared in other ways. Its freedom from carbon and phosphorus makes it ideal as an alloying agent in special steels and nonferrous alloys. Over 70 industrial concerns have tested such manganese, the vast majority finding it superior to the ferromanganese of commerce.

Titanium is estimated to comprise about 0.65 percent of the earth's crust and ranks fourth among metallic elements for structural purposes. In spite of this, its structural applications have not been developed. Commercial exploitation has been confined largely to titanium compounds used in paints and pigments because of the difficulties incident to producing the ductile metal. The occurrence of several important titaniferous deposits led to the investigation of various processes for the preparation of metallic titanium. The unalloyed product has properties analogous to those of stainless steel, with a density one-half as great, opening a field of tremendous metallurgical opportunity. This metal is now being produced in a Government-operated pilot plant and samples of the product distributed to industrial concerns who will cooperate in establishing the uses for which titanium is best adapted.

Ductile zirconium has been produced in limited quantities, and new applications are already apparent. As the cost is lowered, it will undoubtedly replace tantalum in many chemical processing applications and its field of usefulness greatly broadened. The total annual world supply of tantalum in the form of ore is of the order of 600 tons, while zirconium in the form of ore is 100 times more abundant. When the relatively low density of zirconium in comparison to tantalum is considered (it is one-third as great), its engineering possibilities are even more apparent. Samples of this metal will also be furnished outstanding companies who desire to determine its industrial applicability.

Control of prices by processing costs

In many instances the cost of mining ores and minerals represents but a small fraction of the value of the final product. It is the cost of concentrating, smelting, purifying, and fashioning that largely controls the price to the ultimate consumer.

As concrete examples, beryllium in ore is worth 35 cents per pound, $15 per pound in a master alloy, and $75 per pound as beryllium metal. Vanadium is worth 52 cents per pound as ore, $2.80 as ferrovanadium, and $5 as metal. In certain cases, however, these processing methods have been simplified and made so much more efficient that the price of the product has even dropped on a seller's market. Magnesium and aluminum are cases in point. These metals sold during the war at prices appreciably lower than those that prevailed in 1939, and many predict a further decline, yet sea water from which much of the

magnesium is recovered contains only 0.14 percent of this element and represents one of the lowest-grade "ores" ever worked.

Increase of mineral resources by recovery of byproducts

The exploitation of many low-grade mineral deposits has been rendered commercially practicable through the recovery of byproducts. The milling, metallurgical, and chemical processes involved in recovery of such byproducts often appear rather intricate, but they have paid handsome dividends. Thousands of tons of arsenic and many hundreds of thousands of tons of sulfuric acid are recovered annually in the roasting and smelting of lean, metalliferous ores; salt, magnesium compounds, borax, and gypsum are obtained as byproducts in the extraction of potash from the brines of partly desiccated lakes in Utah and California; and obnoxious fluorine gases evolved when phosphate rock is manufactured into fertilizer are now collected and converted into chemical products.

There are many instances where two or more minerals when closely associated are of little or no value, yet each has a ready market when separated from the other. The so-called beach sands of Oregon and those on the Gulf coast of Florida are striking examples. These sands contain substantial percentages of titanium in the form of ilmenite and zirconium in the form of zircon or zirconium silicate. Modern ore-dressing methods have rendered it feasible to separate these two minerals from deposits that otherwise would have no commercial importance.

A very large reserve of vanadium occurs in close proximity to phosphate rock in Utah, Idaho, and Wyoming. The vanadium ore is not high grade, but a process has already been worked out whereby both the phosphoric acid and vanadium values can be extracted from mixtures of the two ores.

Unfinished business

The United States still faces many formidable milling and metallurgical problems, some of which have been partly solved but require further laborious and time-consuming research to bring them to a successful conclusion. There is also ample room for the improvement of existing methods and better utilization of new products.

Experience has proved that the economic advantages of new processes and products must be demonstrated in pilot plants that can be operated on a scale large enough to guide commercial development. Therefore, whenever possible such plants should be built and operated under controlled conditions and the data obtained made available to those seeking to improve existing processes or establish new industries.

STATEMENTS ON MINERAL RESOURCES

Antimony

By J. H. Shaum,[26] D. E. White,[27] and John B. Zadra [26]

The greatest single use for antimony is as an alloying element with lead, to which it adds hardness and mechanical strength. The antimony content of the various alloys ranges from about 1 to about 20 percent. From 1943 through 1944, the only years for which accurate consumption figures are available, almost one-half the primary or newly mined antimony consumed was used in lead-alloy form. In descending order, the principal uses were in batteries, antifriction alloys, type metal, and cable sheathing and in minor products, such as sheet and pipe, castings, collapsible tubes, foil, ammunition, and solder.

The remaining half of primary antimony is consumed in compounds which in the order of importance as of 1944 were antimony oxides, antimony sulfide, sodium antimonate, and antimony trichloride. About 60 percent of the antimony consumed in compounds was used for the manufacture of flame-proofing compounds and the remainder in paints, ceramic enamels, and glass and pottery. It is to be noted that all of these uses are dissipative, whereas a very large part of the alloy returns to the market as scrap metal for reuse, so that in 1944 roughly two-thirds of the antimony content of the total lead-base alloy output was of secondary or scrap-metal origin.

Possible but limited substitutes for antimony are calcium, bismuth, and tin. Calcium has, to a small extent, replaced antimony in some hard-lead alloys. Inasmuch as large quantities are now available, it may be considered a competitor. Bismuth may be substituted for battery use, but its relative high price precludes

[26] Bureau of Mines.
[27] Geological Survey.

any substantial replacement. Tin oxide is often preferred over antimony compounds in the manufacture of ceramic enamels. In some pigments, antimony, cadmium, and titanium are competitive. Cadmium has become of increasing importance in bearing metals as a substitute for antimony.

At no time since 1900 has domestic antimony production exceeded 20 percent of apparent needs. In the period 1910 to 1944 the primary antimony in the United States available for consumption ranged from a low of 4,272 short tons in 1932 to a high of 36,182 short tons in 1943. This compares with domestic production ranging from nothing to as much as 5,556 short tons in 1943. The price of antimony in New York has ranged from 4.92 cents a pound in 1921 to 29.72 cents a pound in 1915. The average price since 1910 has been about 12 cents. Up to 1931, China was by far the major metal and ore supplier, followed by Mexico and Bolivia. About 1931 a Mexican smelter at Wadley, San Luis Potosi, Mexico, was dismantled and reerected at Laredo, Tex. As a result, the United States transferred its dependence from foreign metal to foreign ore, nearly all of which was derived from Mexico and Bolivia. China produced little antimony during its long war with Japan, but Chinese antimony probably will again become important in world markets. In 1944 there were 11 antimony smelters in the United States; metallic antimony was being produced from 4, oxides from 7, and antimony sulfide from 5.

Figure 6 shows the trends in antimony production, consumption, and price in the United States from 1910 to 1944.

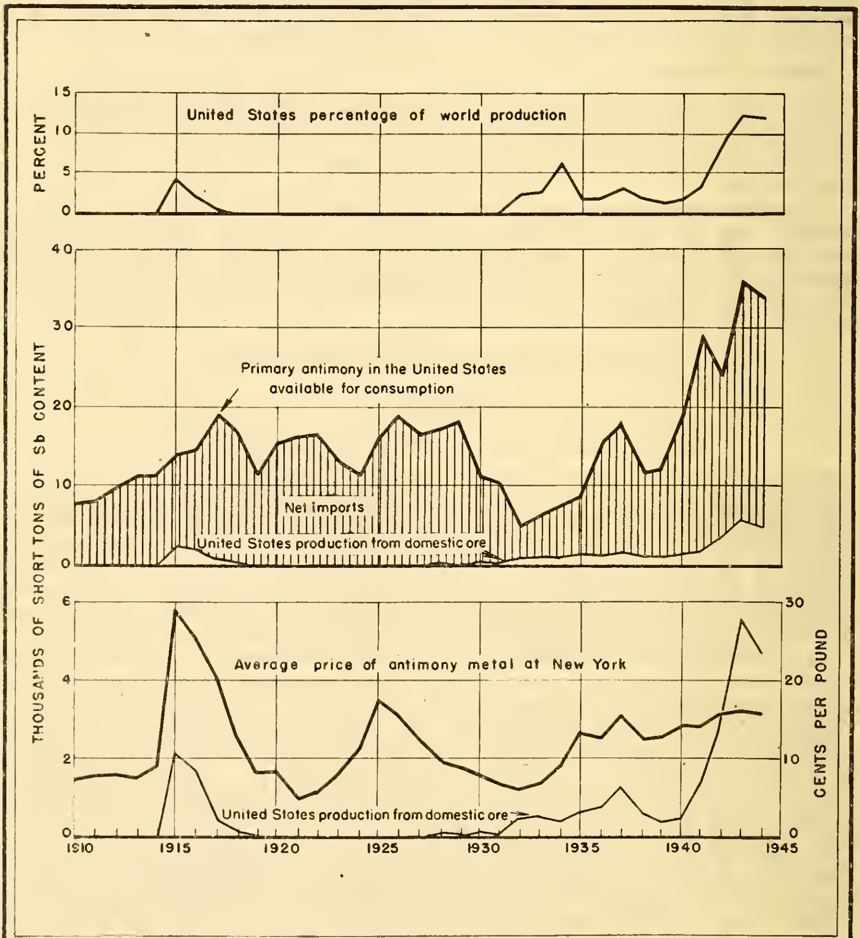

FIGURE 6.—Trends in the consumption, production, and price of antimony in the United States, 1910–44.

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ANTIMONY

MINERAL RESOURCES OF THE UNITED STATES

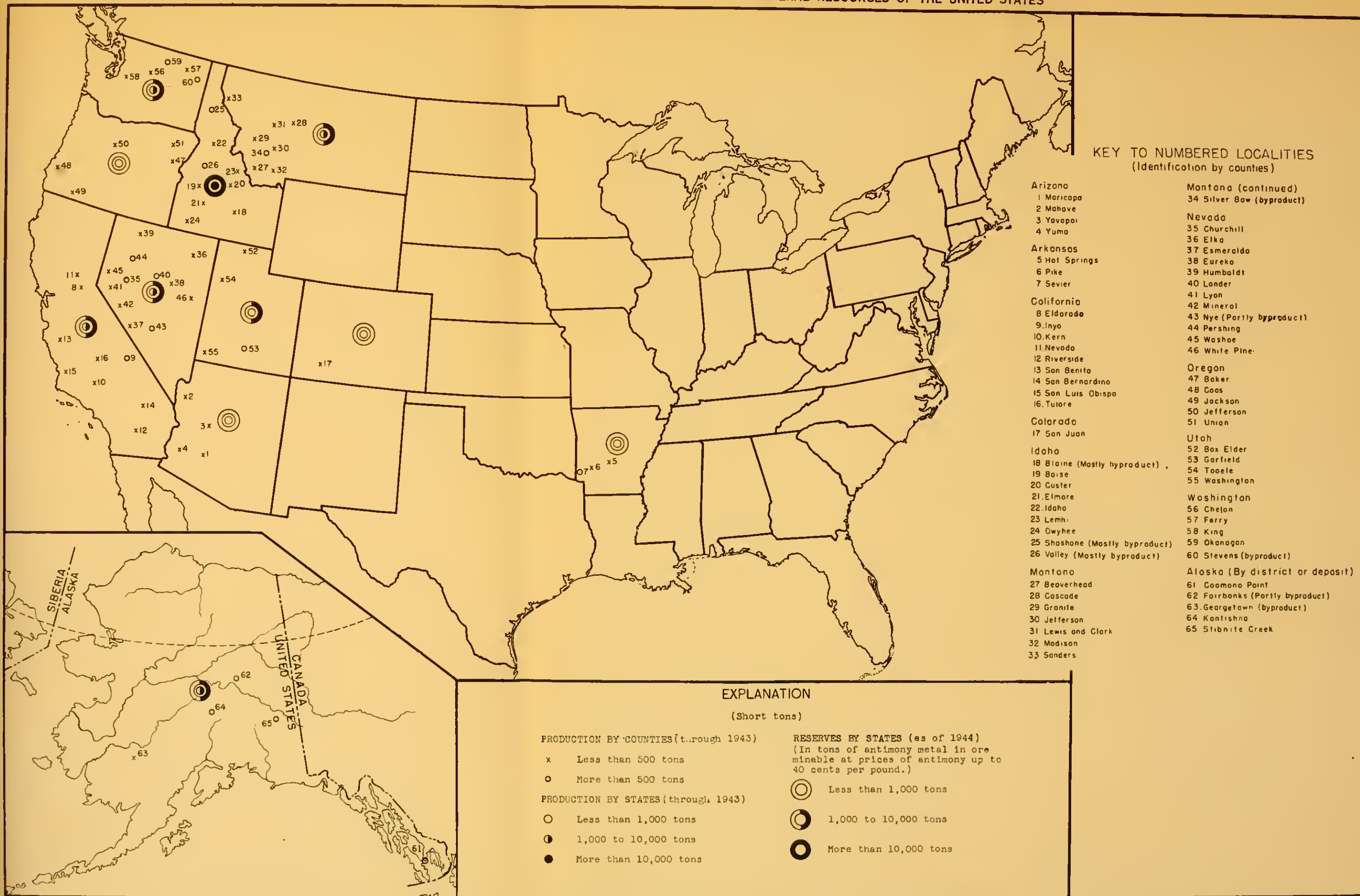

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CHART II.—Distribution of antimony production in the United States and Alaska through 1943, by counties and States, and of reserves in known deposits as of 1944, by States.

The principal domestic source of ore is the Yellow Pine mine in Idaho, in which the antimony ore is a byproduct in the mining of tungsten and gold. Smaller deposits, from which the ore is mined primarily for antimony, occur principally in Alaska, Idaho, Nevada, Oregon, California, Montana, and Washington. Normally, these mines produce only in periods of high prices. The United States has no deposits, from which the ore is mined principally for antimony, that are large enough or rich enough to compete with foreign sources in normal times. Before 1944 such small deposits yielded 10,200 short tons of metallic antimony, or 24 percent of this country's total production, as contrasted with 31,500 tons, or 76 percent of the total, from mines in which the antimony was recovered as a byproduct. Although production from mines yielding only antimony shows a direct relationship to the market price for antimony, there is little such relationship in the case of production from byproduct mines, for the operation of these mines depends primarily on the prices received for the principal metals. This means that the simple expedient of raising prices for antimony does not result in comparable increases in production.

Reserves

Domestic reserves of antimony, as shown in table 1, are segregated into (*a*) material minable under conditions as in 1944, when the average price was 16 cents a pound, and (*b*) material minable under conditions of extreme emergency, with prices as high as $1.50 a pound. The sum of these two classes represents the total estimated recoverable reserves. The measured and indicated reserves are given together because available information does not permit segregating them reliably. The distribution of known antimony deposits is pictured in chart II, which shows also the distribution of reserves that would be minable at prices up to 40 cents a pound. The price of 40 cents a pound is arbitrarily chosen as a probable economic maximum.

TABLE 1.—*Reserves of antimony in the United States as of 1944*

[In short tons]

	Measured and indicated ore		Inferred ore		Total antimony content, tons
	Tons	Antimony content, tons	Tons	Antimony content, tons	
Minable at 16 cents per pound—					
From antimony deposits	10,000	[1] 980	5,000	520	1,500
As byproduct ore	4,300,000	42,000	900,000	11,000	53,000
Total	4,310,000	[3] 43,000	905,000	[3] 11,500	54,500
Minable at 17 cents to $1.50 per pound—					
From antimony deposits	500,000	[2] 5,000	750,000	15,000	20,000
As byproduct ore	8,600,000	23,000	2,700,000	6,000	29,000
Total	9,100,000	28,000	3,450,000	21,000	49,000
Grand total	13,410,000	71,000	4,355,000	32,500	103,500

[1] 280 tons measured and 700 tons indicated.
[2] Nearly all indicated.
[3] Round numbers.

The Yellow Pine mine in Idaho contains nearly 70 percent of the reserves minable at 16 cents a pound and over 50 percent of the total reserves. The high-grade tungsten ore in this mine also has the highest antimony content but is low in gold. The most-abundant type of ore contains gold, with some antimony. In these ores the antimony, regardless of its value, is mined with the tungsten and gold and will be marketed as long as its value exceeds the cost of its special handling. About 20 percent of the remaining reserves, in tons of ore, contains a sufficient amount of gold to be mined at a profit under 1944 prices but contains negligible amounts of antimony and tungsten. In the remaining reserves that contain antimony as an appreciable constituent, the gold content is too low for the ore to be mined for gold alone under 1944 prices. The mining of these reserves therefore depends on a sufficiently high price for the antimony.

Reserves for the country as a whole, stated in table 1 as minable at a price of 16 cents a pound for the antimony, are but little more than total estimated past mine production of about 42,000 tons of antimony, and total reserves are only about 2½ times as large as past production. The production in 1943 of recoverable antimony from antimony ore—5,556 tons—probably will mark the all-time maximum peak of production of antimony in the United States because of the large-scale mining of the high-grade tungsten and antimony ore of the Yellow Pine mine in that year. Indeed, in 1944 the output had already declined to 4,735 tons and in the future can rarely be expected to exceed 2,500 tons per year. After the reserves of the Yellow Pine mine are exhausted, normal production probably will fall to less than 1,500 tons per year unless new, rich deposits are discovered. Inasmuch as only one mine very highly productive of antimony has been discovered in the history of this country, the possibility for spectacular new discoveries must be considered remote.

Arsenic

By W. S. Burbank,[28] Allan F. Matthews,[29] and McHenry Mosier [29]

Arsenic, principally in the form of white arsenic (arsenic trioxide), is used in the manufacture of insecticides, such as calcium arsenate, lead arsenate, and paris green. Large quantities of arsenic are also utilized for manufacturing glass and killing weeds. It is used to a minor extent in wood preservatives, dyes, nonferrous alloys, pharmaceuticals, and paint. A wide variety of chemicals can be substituted, with varying degrees of efficiency, for arsenical insecticides, and antimony and cerium may be substituted in glass manufacture. There is no recorded recovery of arsenic from scrap.

Normally, the domestic output of arsenic is inadequate to meet demands. The chief foreign sources in recent years have been Mexico, Canada, and Peru, but before World War II considerable arsenic was imported from Sweden, France, and Japan. Other potential sources in this hemisphere include Brazil, Ecuador, Chile, and Cuba. Much of the production from this hemisphere is from arsenic-bearing gold ores, and although reserves of such ores are doubtless adequate to meet normal requirements, any appreciable increase in demand probably would necessitate new facilities for the recovery and refining of arsenic. Sweden contains one of the world's largest reserves of arsenic-bearing ores. Normally, Australia, Belgium, and Germany also produce arsenic, and other countries record minor production. Potential sources exist in Southern Rhodesia, Burma, and the Philippine Islands.

In normal times domestic output is a byproduct in the smelting and treatment of arsenic-bearing ores of domestic and foreign origin. The primary sources of the arsenic are therefore considerably obscured, and the ores that yield the bulk of the production are known only in a general way. The principal smelters producing arsenic are those of the American Smelting & Refining Co., the Anaconda Copper Mining Co., and the United States Smelting, Refining & Mining Co., whose primary sources are the arsenical copper ores of Butte, Mont., and the various lead, copper, and gold ores of the Western States and British Columbia. The Getchell mine in Nevada and the Jardine mine in Montana also have yielded considerable arsenic from their own plants, in which the ore is roasted in the course of recovering gold and other metals.

Emergency demands for arsenic, either in wartime or for special agricultural needs, occasionally have prompted a small amount of direct production from a few relatively high grade deposits of arsenic ore. Such sources include the Gold Hill district, Utah, and several smaller deposits in Nevada, California, Colorado, Idaho, Virginia, and elsewhere. None of these deposits, however, can be exploited profitably in competition with byproduct arsenic.

Chart III shows the distribution of (1) the principal plants producing marketable white arsenic as a byproduct from the treatment of ores of other metals, chiefly those of copper, lead, and precious metals; (2) a plant producing crude arsenic trioxide, which is shipped for refining at white-arsenic plants; (3) districts containing arsenical ores of gold and silver that have yielded, or in emergencies could yield, arsenic as a byproduct in the process of extracting other metals; and (4) districts containing ores chiefly of value for their arsenic but including some deposits on which data as to other metals are not available.

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[28] Geological Survey.
[29] Bureau of Mines.

ARSENIC

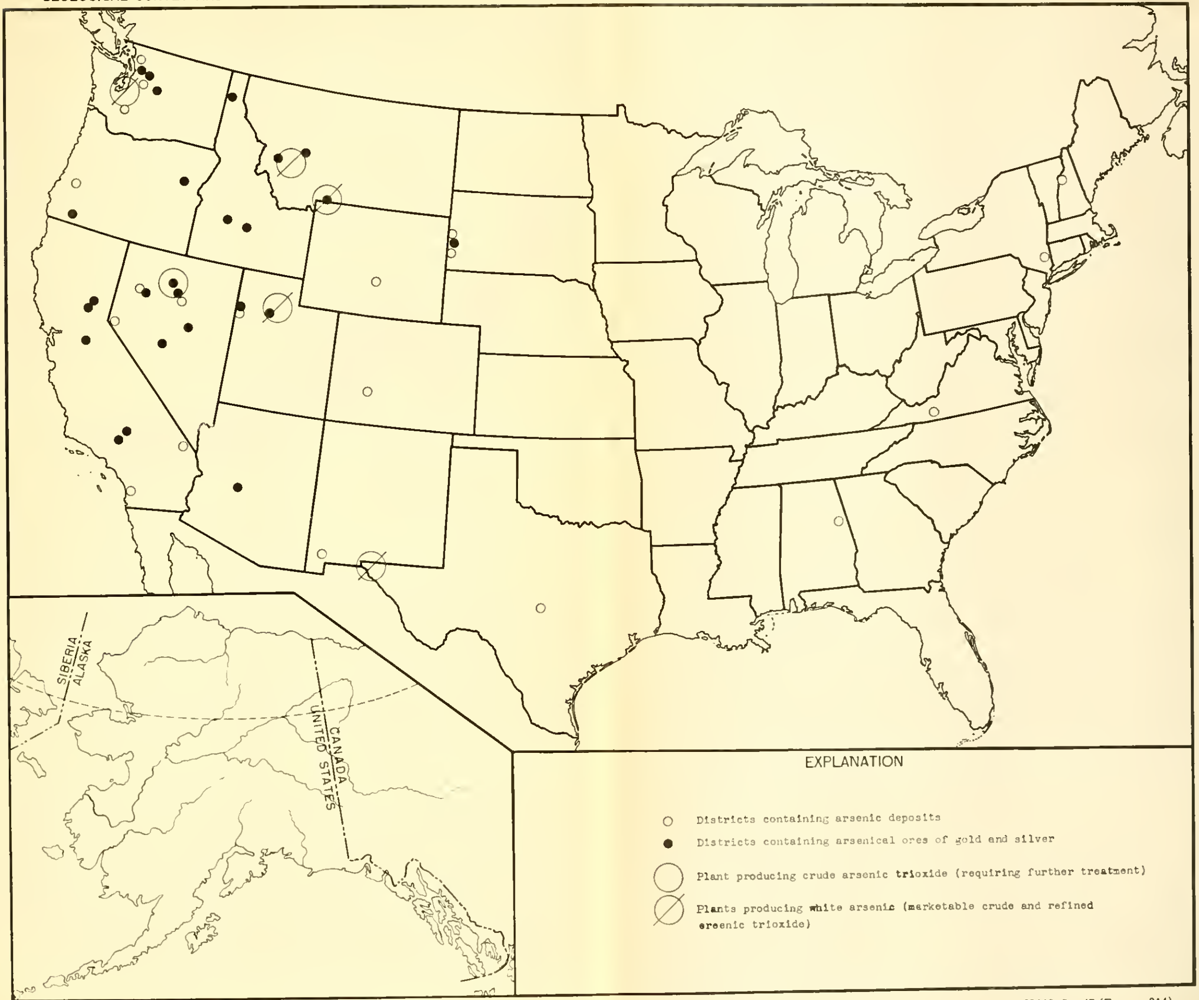

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CHART III.—Distribution of arsenic resources of the United States and plants producing crude and white arsenic as of 1944.

The course of production of white arsenic in the United States, which began in 1901, is shown in figure 7. The price for crude white arsenic has ranged from

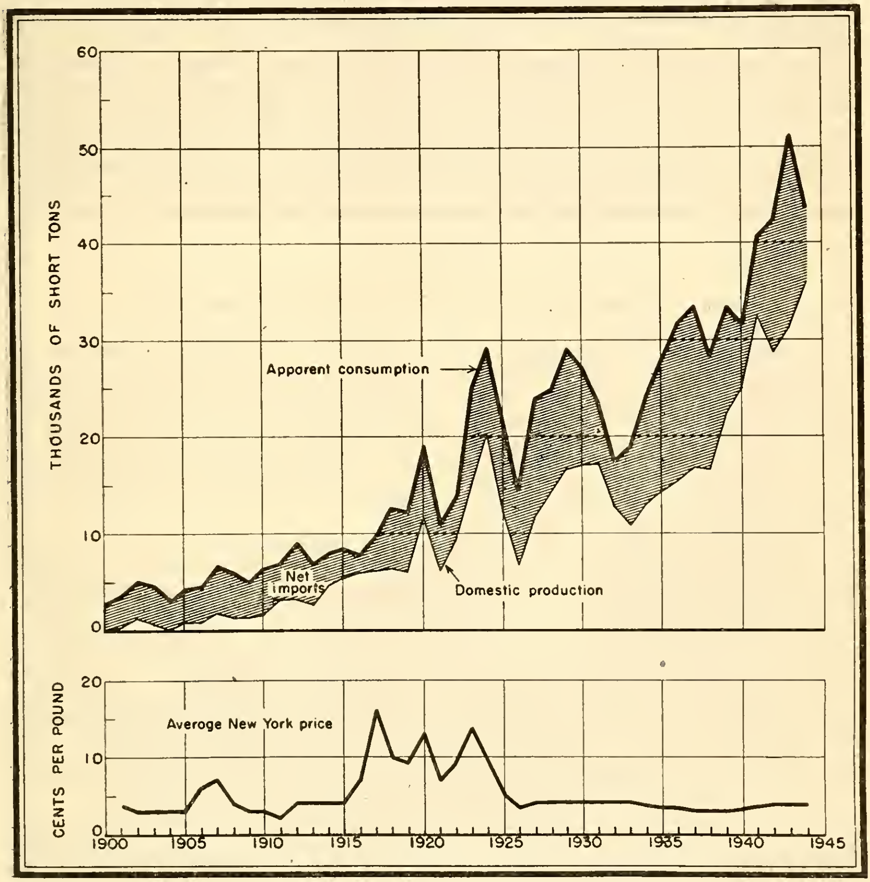

FIGURE 7.—Apparent consumption, domestic production, and price of white arsenic (As_2O_3) in the United States, 1900–1944

1½ cents a pound in 1911 to a temporary high of 20 cents a pound in May and July 1917. Since 1926 the price has been nearly constant at 3 to 4 cents and unrelated to production trends. Consumption depends primarily upon the need for insecticides and, to a smaller extent, upon the activity of the glass industry, and shows little relationship to price.

Reserves

Domestic reserves comprise three principal classes: (1) Ores that yield arsenic as a byproduct of smelting operations, including those of copper, lead, zinc, silver, and gold; (2) ores that could yield arsenic directly in connection with milling or other treatment for other valuable metals, chiefly gold and silver, as at the Jardine mine in Montana and the Getchell mine in Nevada; and (3) arsenic ores whose value depends solely upon the arsenic content. The economics and technology of arsenic recovery from the three classes of ores vary considerably. Arsenic is produced most cheaply from ores in class 1. For class 2, the recovery of arsenic is not economic, except at deposits having an arsenic content of at least 4 percent. Only ores of class 1 and a small fraction of the ores of class 2 are available as sources of arsenic under present economic and technologic conditions. Domestic smelter operations in recent years have yielded 60 to 70 percent of United States needs.

The reserves of class 1 (smelting ores tributary to reduction plants) are estimated to contain about 1 million tons of recoverable white arsenic. This is equivalent to about 30 years' supply at the capacity of present smelting plants. An additional million tons of white arsenic is estimated to be available from class 2 ores.

Reserves of high-grade arsenic ore (20 percent or more (As_2O_3)) of class 3 are extremely limited in comparison with the reserves of smelting ores. High-grade ores probably total several million tons, including inferred reserves and considering only reasonably large bodies. In this class of ores where arsenic is the principal product, there are also enormous reserves of low-grade ores containing the equivalent of at least 5 percent white arsenic. However, the probable utilization of this low-grade material is so remote that substitutions for some of the uses of arsenic, especially for insecticides, are much more probable.

Asbestos

By Oliver Bowles,[30] L. W. Currier,[31] and W. H. Waggaman [30]

The outstanding characteristics that give asbestos industrial value are its fibrous structure, which permits it to be spun, woven, or felted, and its incombustibility. Thus it can be employed like organic fibers for making textiles and other products that have the advantage of being fire resistant. Because of their fibrous nature, the woven or felted products are good heat insulators.

There are several varieties of asbestos and various grades or qualities of each kind. Chrysotile is the principal variety of commerce, and the bulk of the consumption is of the shorter fibers used in making asbestos-cement building materials and various types of insulating products.

The strategic grades of asbestos are primarily the low-iron chrysotile obtainable chiefly in Rhodesia (with small quantities available in Arizona) and the amosite and blue varieties of amphibole asbestos, virtually all of which originate in the Union of South Africa. The low-iron chrysotile is needed primarily for electrical tapes and other products where electrical insulation is essential. Chrysotile containing considerable iron oxide, like that occurring in Canada, can be used in place of the low-iron types where low-tension electric currents are involved, hence the longer Canadian fibers may also be regarded as significant strategically. Furthermore, long-fiber chrysotile, irrespective of its iron content, has important uses—for making brake bands and other friction accessories, particularly for automotive equipment, also for fire-resistant suits, shoes, and gloves, and for making packings and gaskets essential to power plants and factories; thus any long-fiber chrysotile has strategic importance.

Amosite is needed for 85-percent magnesia and other pipe covering, for fireproof building partitions like those on ships, for underground steam-pipe insulation that will resist corrosion, and for flocculent insulating material of low volume weight, particularly for use on naval vessels. Blue asbestos is acid resistant and therefore has certain essential uses in the chemical and processing industries. Moreover, it is superior to other varieties for spraying walls and steelwork to provide a heat-insulating and fire-resisting coating. Long blue asbestos is needed in gas masks. Blue fiber is also used extensively in making asbestos-cement pipe and building materials.

Canada is the principal source of chrysotile asbestos, but large quantities are produced also in Rhodesia, Swaziland, and Soviet Russia.

Statistical data are not available for constructing a historical chart of consumption of strategic grades only; furthermore, domestic production of these grades is too low to be significant. Figure 8 has been prepared covering domestic production and consumption of all grades and varieties. Although large quantities of the nonstrategic grades are included in this presentation, it portrays clearly the Nation's overwhelming dependence upon foreign supplies.

Occurrences of chrysotile are known in many States, but none of the deposits promises substantial supplies of long fibers. The United States produces only 4 to 8 percent of its requirements of all grades, and only a small fraction of that produced is of the long-fiber type. No amosite or blue fibers are obtainable in the United States.

[30] Bureau of Mines.
[31] Geological Survey.

The only consistent producers of asbestos in the United States are in Vermont and Arizona. Vermont has substantial reserves of chro and carolino. entire production from this State is of the short-fibergrades that are not classed as strategic. In 1944 a new quarry was opened from which considerable quantities of long-fiber asbestos (slip-fiber variety) are obtained, but the process of fiberizing this material and subsequent handling are so difficult that the material is processed into the shorter grades. Until the operating difficulties that now prevent its use as long fiber are solved, the material is not to be regarded as of strategic grade.

Arizona produces small quantities of low-iron, long-fiber chrysotile of good quality, but there is little prospect of a substantial increase in supply from this source.

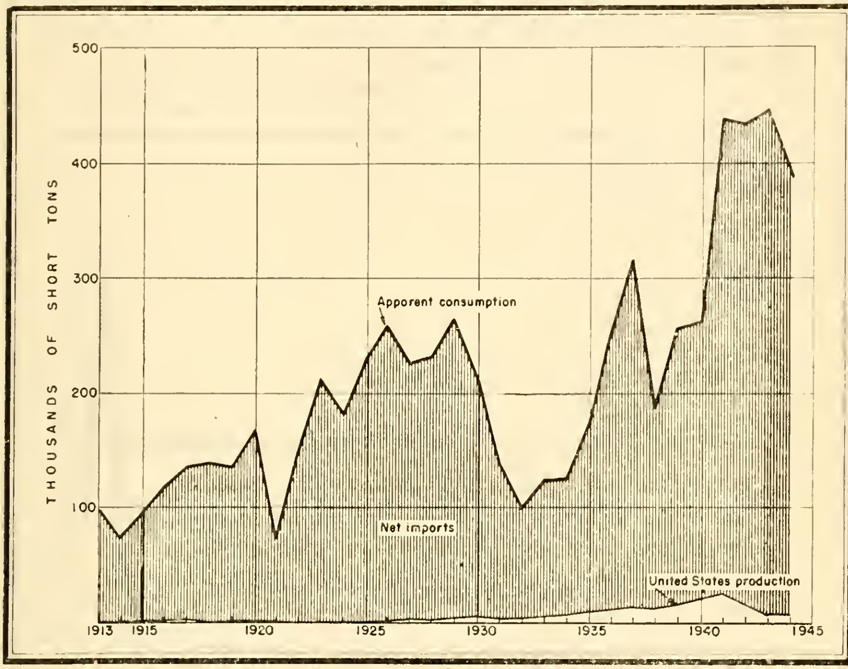

FIGURE 8.—Trends in production, net imports, and apparent consumption of all grades of asbestos in the United States, 1913–44.

Reserves

Because of the generally inadequate data on the extent of chrysotile deposits in the United States, or the quality or grade of the contained asbestos, estimates of reserves are only approximate. On the basis of present information it is believed that the United States reserves of chrysotile asbestos of all grades total about 750,000 short tons, of which not more than 4,000 tons consist of long fiber. The annual domestic demand for long-fiber chrysotile is about 17,000 tons.

BAUXITE AND OTHER SOURCES OF ALUMINUM

By Josiah Bridge,[32] John B. Dorsh,[33] and John H. Weitz[33]

Bauxite is by far the most important ore of aluminum, and because of the widespread use of aluminum in aircraft and the vital importance of aircraft in modern warfare, bauxite has become a strategic raw material of international significance. Because of its light weight and its strength, aluminum has enjoyed a persistent growth in industrial use in many applications besides aircraft, and that growth may be expected to continue for some time in the future.

In addition to its status as an ore of aluminum, bauxite has many other uses, including the manufacture of chemicals, abrasives, refractories, and cement,

[32] Geological Survey.
[33] Bureau of Mines.

it is employed in oil refining, and as a flux in the steel and ferro-alloy industries. Before World War II, approximately 75 percent of the bauxite consumed in the United States was converted to refined alumina, chiefly for use in manufacturing aluminum. During the war the proportion used in the manufacture of alumina rose—to nearly 90 percent in 1943. In the postwar period, this proportion will decline considerably because of the sharp drop in requirements of aluminum for aircraft construction, but it probably will remain above the prewar level.

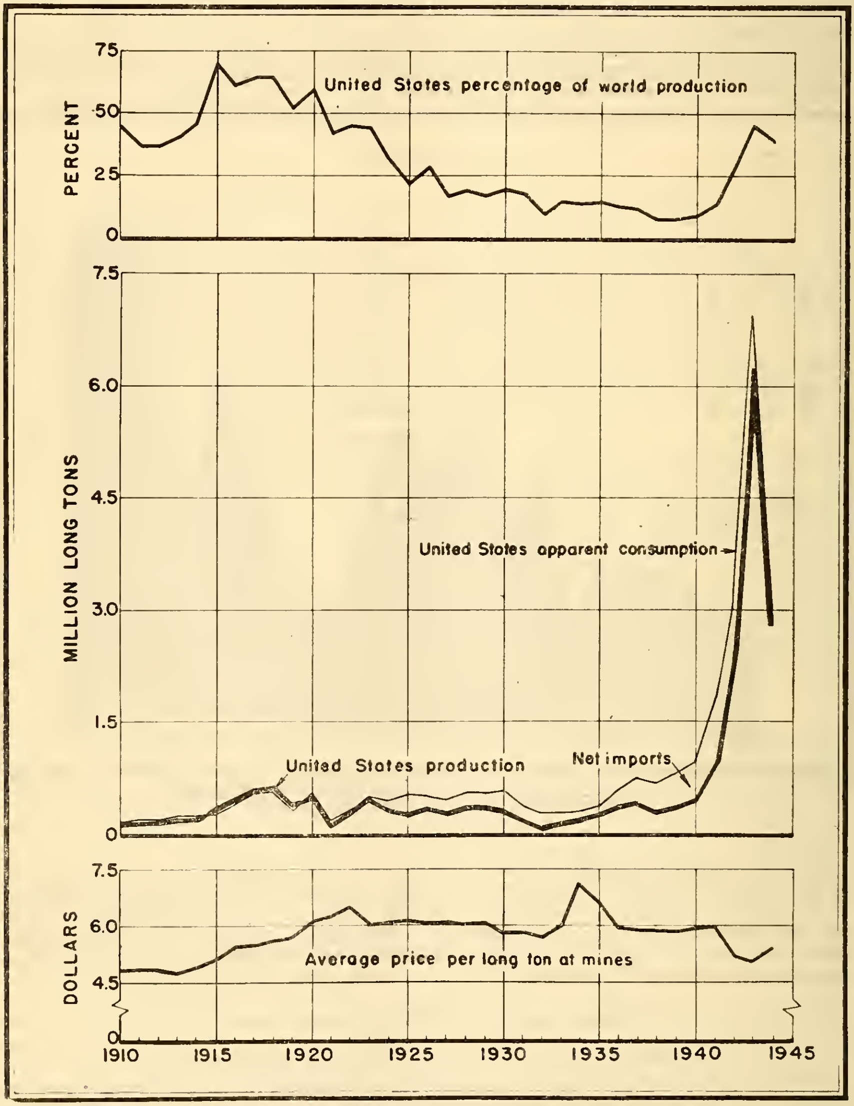

FIGURE 9.—Trends in production, apparent consumption, and price of bauxite in the United States, 1910–44.

Figure 9 shows the trends in domestic production, the apparent consumption, and price of bauxite from 1910 to 1944. From 1925 to 1941 domestic production and net imports were approximately equal. The sharp rise in production thereafter reflects the stimulation of domestic output, chiefly of substandard-grade ores, necessitated by war shipping difficulties. Much of this output was stockpiled by the Government as an emergency supply, so that the apparent consumption shown for these years is considerably higher than actual consumption.

Figure 10 shows the trends of production, the apparent consumption, and prices of aluminum metal in the United States from 1910 to 1944. The substantial and persistent growth of the industry before 1940, as shown in the graph, is dwarfed by its phenomenal rise during the war. Immediate postwar demands for primary metal may decline to less than 500,000 short tons per year, although later

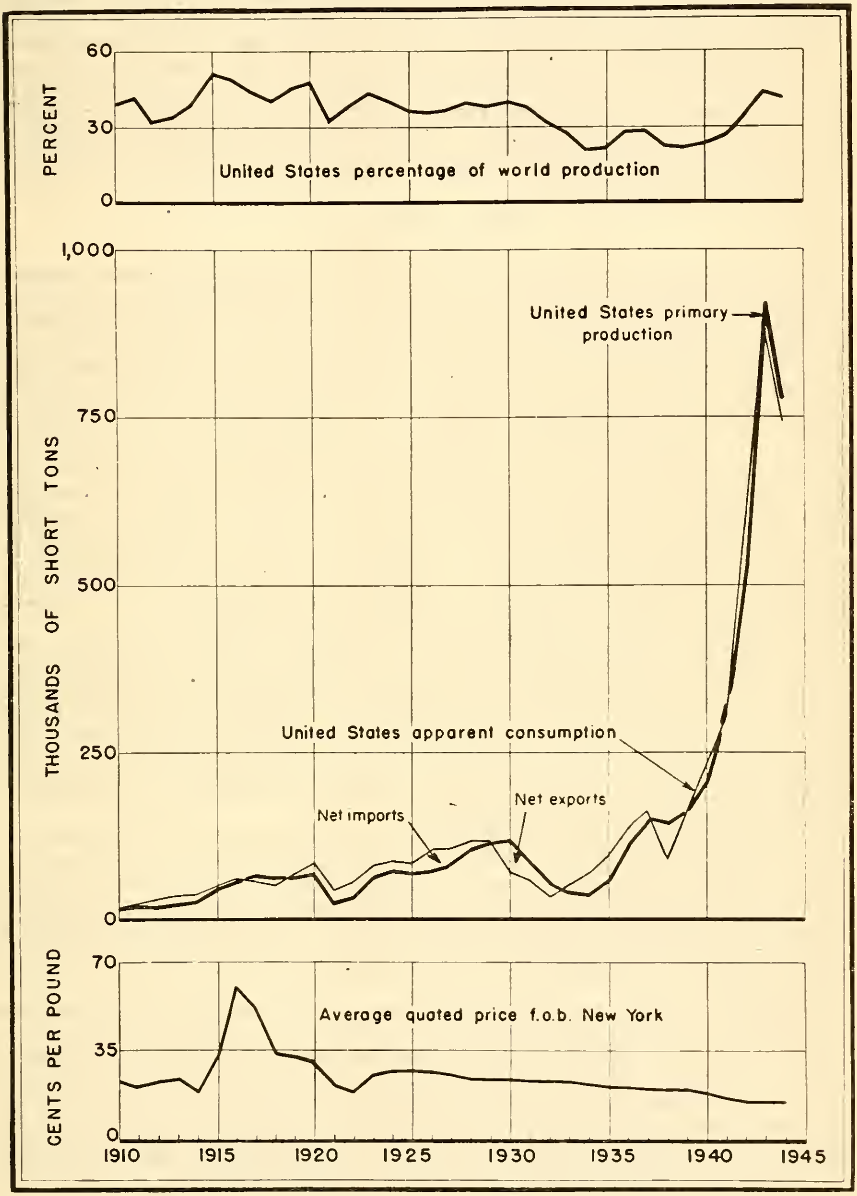

FIGURE 10.—Trends in production, apparent consumption, and prices of aluminum metal in the United States, 1910–44.

a larger annual consumption is certain to develop. Many uses of aluminum do not result in undue dissipation of the metal, so that there is a large return of scrap. In 1944 the recovery of aluminum from scrap was equivalent to 42 percent of virgin-metal production. Considerable bauxite is thus conserved by the efforts of the metal-reclaiming industries.

Before the war, commercial alumina (calcined aluminum oxide recovered from the ore, and the material from which aluminum is made) was recovered in the United States entirely from high-grade bauxite, substantial quantities of which were imported to augment inadequate domestic production. The war emergency stimulated intense research on the possible use of (1) red mud, a waste product of the Bayer process used in refining bauxite; (2) impure or low-grade bauxite; (3) clays containing a high percentage of aluminum, commonly called bauxitic and high-alumina clays; (4) alunite, a sulfate of aluminum and potassium found at a few places in the Western States; and (5) anorthosite, a rock found in large quantities at a few localities. Some of the lower-grade bauxites probably will be used commercially in the near future. However, there has been no domestic commercial production of alumina from the other potential sources, and unless or until cheap processes are developed to utilize the lower-grade domestic materials, a large measure of dependence on foreign sources of high-grade bauxite may be expected to continue.

DOMESTIC RESOURCES

Bauxite

Domestic bauxite is essentially a mixture of two aluminum minerals—gibbsite (aluminum trihydrate) and kaolinite (hydrated aluminum silicate)—and various impurities. There is no generally accepted definition of bauxite as an aluminum ore. Before 1941 only bauxite containing not more than 7 percent of silica was used for the production of alumina, which in the United States was accomplished entirely by the Bayer process. War-time modifications in this method of recovery theoretically permitted the use of bauxite averaging as much as 15 percent of silica; but in actual practice the highest monthly average of the silica content has been only 12.4 percent. As defined by the War Production Board in 1942, bauxite to be classed as an ore of aluminum must contain not more than 15 percent of silica (SIO_2), not less than 40 percent of alumina (Al_2O_3), and not less than 32 percent of "available alumina," a term used in the industry to indicate the alumina theoretically recoverable from any aluminum ore by the particular process to be used in treating the ore. When bauxite is to be treated by the Bayer process, the presence of silica makes part of the alumina unrecoverable; consequently, the available alumina is calculated by subtracting from the total alumina content an amount equal to 1.1 times the silica content.

The domestic bauxite deposits occur in the eastern United States in the Gulf Coastal Plain from Arkansas to Georgia (see chart IV) and in the Appalachian Valley from Alabama to Virginia. The principal deposits are in Arkansas, and in 1943 they contributed about 97 percent of all bauxite mined in the United States and about 99 percent of that mined for the production of alumina. The deposits of the eastern Gulf Coastal Plain rank second in production, but the greater part of the bauxite mined there is used in the chemical and refractory industries because of its high silica and low iron content. The Appalachian Valley field is already nearly exhausted.

In no other place in the United States or its Territories are large deposits of bauxite known or likely to be found. In the favorable areas the chances of discovering large new fields are remote. On the other hand, some of the current rejected material from mining bauxite of a grade lower than that used for metal production during the war may become usable. At that time both the material surrounding the higher-grade deposits and individual low-grade deposits will become valuable if they have not been made unavailable by previous mining operations.

Tables 2 and 3 show the several classes of bauxite reserves, including material available under 1944 and possible future conditions. Except with respect to ferrous iron (FeO) content, only bauxite that meets the 1942 specifications of the War Production Board is considered in this report as "aluminum ore" under economic conditions that prevailed in 1944. These specifications require that the ore shall contain less than 6 percent of ferrous iron, but most analyses of reserves do not report ferrous iron separately from total iron. Between 40 and 50 percent of the Arkansas bauxite listed in the accompanying tables is estimated to contain more than 6 percent of ferrous iron (grade III), and thus cannot be considered an available reserve under 1944 conditions.

It is assumed that no deposit or parts of deposits less than 5 feet thick will be mined, and such bodies are excluded from the estimate. For lack of adequate information, measured and indicated reserves are grouped for some areas.

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BAUXITE AND OTHER SOURCES OF ALUMINUM

MINERAL RESOURCES OF THE UNITED STATES

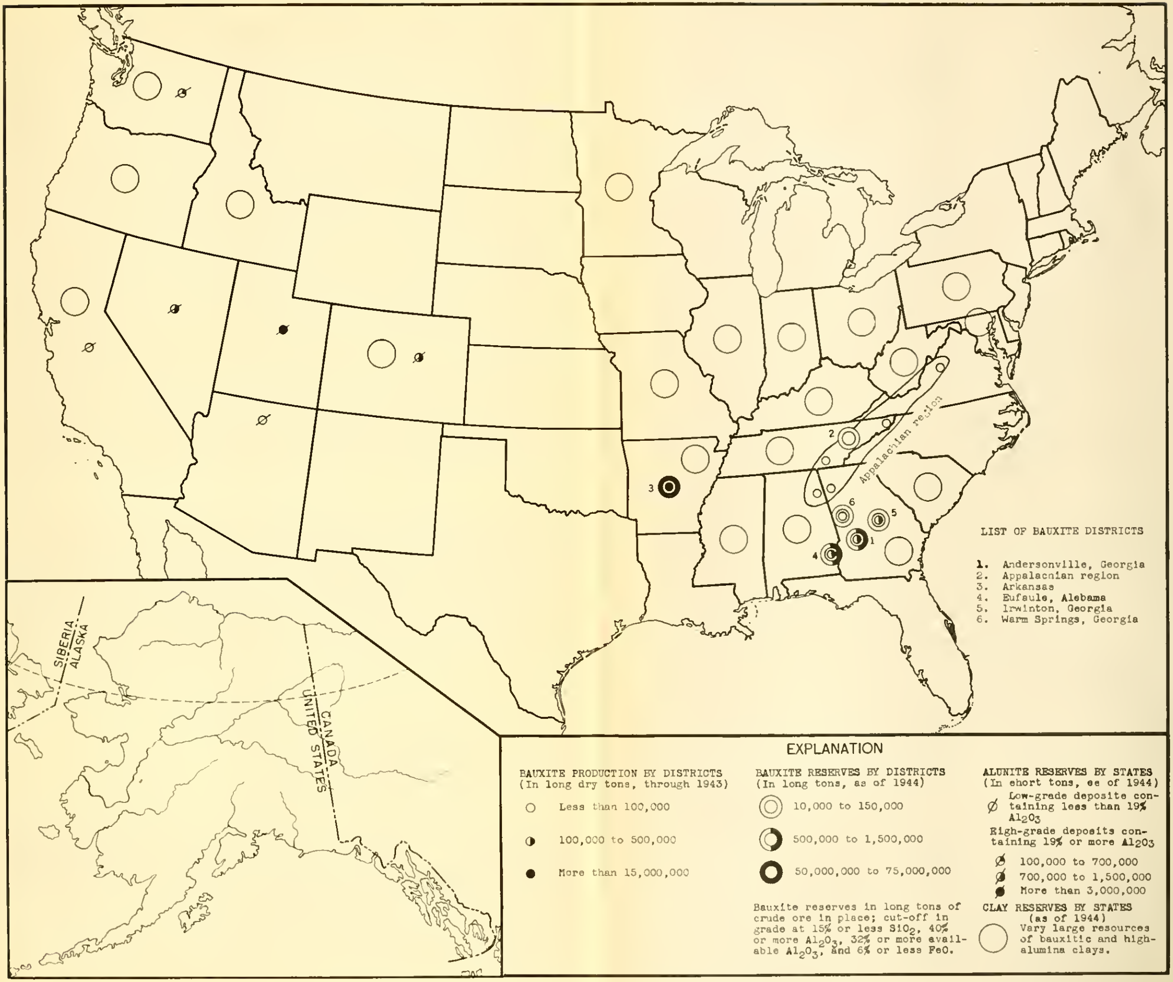

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CHART IV.—Distribution of bauxite production before 1944 and estimated reserves in the United States, as of 1944, by districts, and of alunite and clay reserves, by States.

It has been assumed that 85 percent of the material in the ground can be mined where open-pit methods are used and 65 percent where underground mining must be used. In estimating reserves available under conditions in 1944 all material in the coastal areas of Alabama and Georgia under an overburden greater than 50 feet has been excluded. Such deposits would have to be mined by underground methods at higher cost, and stripping more than 50 feet of overburden would be uneconomical. As much as 5 million long tons have been excluded for this reason—over 4.5 million tons of which is in the Andersonville district, Ga.

Low-grade bauxite.—Bauxite that contains 24 to 32 percent of "available alumina" is the highest grade of the remaining potential sources of aluminum. Unfortunately much of it is wasted in mining higher-grade bauxite by present methods. Reserves of this material are included in those of bauxitic and high-alumina clays because of inadequate data for estimating them separately.

Bauxitic and high-alumina clays.—For the purpose of this report bauxitic clay is defined as bauxitic material containing 24 percent or less of "available alumina" for the Bayer process. The total alumina content varies, but usually exceeds 35 percent, depending on the quantity of impurities present. High-alumina clay is defined as clay containing at least 30 percent of total alumina. So many processes are being considered for the treatment of high-alumina clay that the content of "available alumina" has no uniform significance. The geographic distribution of such deposits is shown on the map, chart IV, and in table 2 bauxitic clay is found only at a few localities outside of the main bauxite areas, but high-alumina clays are widely distributed. For the purpose of these estimates only material in beds 5 feet or more thick having a ratio of overburden to clay of 4 : 1 or less is included.

Processes for extracting alumina from this material are still in the experimental and pilot-plant stages. Consequently the grade or grades of material that may eventually constitute ore have not been defined, and the definitions given above represent only the prevailing opinion of metallurgists of the Bureau of Mines as to what may become usable as processes are developed. In 1944 two semicommercial plants for the production of alumina from clay had been completed, but few operating data were available. Efficiency and cost will determine the future acceptance of these processes on a large scale.

Alunite

The alunite deposits of the United States occur both as veins of high-grade material and as altered volcanic rocks containing disseminated particles or masses of alunite. Those in Utah were used as a minor source of potash during the First World War. During World War II the Defense Plant Corporation built an experimental plant at Salt Lake City with a rated capacity of 100 tons per day to extract alumina from alunite. This plant began operating in 1943 and was shut down in 1945. Owing to relatively limited domestic alunite resources, this raw material will never be an important factor in the aluminum industry in the United States. The principal alunite deposits are at Marysvale, Utah; smaller deposits are known in Colorado, Nevada, Washington, Arizona, and California. Table 3 summarizes the alunite reserves of the United States.

TABLE 2.—*Estimated reserves of bauxitic and high-alumina clays in the United States as of 1944, by areas* [1]

[In short tons]

Area	Measured and indicated reserves			Inferred reserves
	Measured	Indicated	Total	
Eastern—chiefly Alabama, Georgia, South Carolina, and Pennsylvania	25,000,000	90,000,000	115,000,000	3,000,000,000 minimum
Central—chiefly Arkansas, Colorado, etc.	15,000,000	80,000,000	95,000,000	
Western—chiefly California, Washington, Oregon, and Idaho	100,000,000	65,000,000	165,000,000	
Total	140,000,000	235,000,000	375,000,000	3,000,000,000

[1] Reserves of bauxitic clay include all material containing 24 percent or more of "available alumina"; reserves of high-alumina clay include all material containing 30 percent or more of total alumina.

TABLE 3.—*Estimated reserves of alunite in the United States as of 1944, by States* [1]

[In short tons]

State	Measured	Indicated	Inferred	Total
Utah	2,870,000	500,000	370,000	3,740,000
Colorado	400,000	450,000	600,000	1,450,000
Nevada	177,000	143,000	394,000	714,000
Washington	43,000	59,000	95,000	197,000
Total	3,490,000	1,152,000	1,459,000	6,101,000

[1] Includes all material containing 19 percent or more of Al_2O_3. The average grade of this material is estimated at 20 percent of Al_2O_3.

Anorthosite

Anorthosite is an igneous rock containing 29 to 32 percent of alumina. A semicommercial plant to test the feasibility of extracting alumina by a lime-soda-sinter process was constructed by the Monolith Midwest Portland Cement Co., using Reconstruction Finance Corporation funds, at Laramie, Wyo., in 1943; the plant had not yet been put on a production basis by the end of 1944.

Summary

Reserves of high-alumina materials, exclusive of anorthosite, considered in 1944 as potential ores, totaled 3 billion tons, containing 356 million short tons of recoverable aluminum, as shown in table 4. Of the latter quantity, only 3 percent, or about 11 million tons, was in material (bauxite, grades I and II) considered ore in 1944. In 1943 the United States actually used approximately 750,000 short tons of aluminum. A little over 2 percent, or 8 million tons, is in high-iron bauxite; 0.15 percent, or about 500,000 tons, in alunite; and 95 percent in low-grade bauxite, bauxitic clay, and high-alumina clay. The United States has very small reserves of grade I bauxite (see tables 5 and 6), which was used exclusively in this country for the production of aluminum before the war. Recent technologic advances probably made grade II bauxite commercially available, but known reserves are not large in terms of long-term national requirements. The Nation's aluminum resources in the lower-grade bauxites and clay are enormous, but it will probably be cheaper to import high-grade foreign ores than to extract alumina from low-grade domestic material. However, it provides an emergency source of supply that could be used if supplies of the higher-grade bauxites are cut off at any time in the future. In an emergency it could supply the entire national requirement for a considerable period if the increased cost of processing is not a controlling factor.

TABLE 4.—*Aluminum recoverable from bauxite, high-alumina clays, and alunite reserves estimated in the United States in 1944*

	Aluminiferous material		Alumina (percent)		Available alumina (short tons)	Aluminum metal [1] (short tons)
	Long tons	Short tons	Total	Available		
Bauxite:						
Grade I [2]	5,924,000	6,635,000	59	52	3,450,000	1,725,000
Grade II [2]	37,869,000	42,413,000	52	41	17,389,000	8,694,000
Grade III [2]	35,002,000	39,202,000	50	40	15,681,000	7,841,000
Total	78,795,000	88,250,000	52	41	36,520,000	18,260,000
Low-grade bauxite, Bauxitic clay, High-alumina clay	3,013,000,000	3,375,000,000	[3] 32	[4] 20	675,000,000	337,500,000
Alunite	5,447,000	6,101,000	20	[4] 16	976,000	488,000
Total aluminiferous material	3,097,242,000	3,469,351,000			712,496,000	356,248,000

[1] Conversion factor of alumina to aluminum, 50 percent.
[2] For specifications, see table 5, footnote 1.
[3] Estimated average.
[4] Conjectural; dependent upon development of practical processes.

TABLE 5.—*Bauxite reserves of the United States as of 1944, by States or regions*

[In long tons]

State or region	Grade ore[1]	Average content		Reserves in deposits 8 feet or more thick				Reserves in deposits 5 feet or more thick			
		SiO_2 (percent)	Al_2O_3 (percent)	Measured	Indicated	Inferred	Total	Measured	Indicated	Inferred	Total
Arkansas	I	6	59	(2)	(2)	(2)	5,000,000–6,500,000	(2)	(2)	(2)	–6,000,000 7,500,000
	II	10	52	53,444,000		5,500,000	58,944,000	58,788,000		5,500,000	64,288,000
	III	9	50	84,141,000	13,019,000	10,000,000	107,170,000	92,350,000	14,538,000	10,000,000	116,888,000
East Gulf Coastal Plain:											
Alabama	I	5.6	60	(2)	(2)	(2)	30,000	(2)	(2)	(2)	40,000
	II	12	56	----------	300,000	200,000	500,000	350,000		200,000	550,000
	III	13	56	----------	350,000	250,000	600,000	420,000		250,000	670,000
Georgia	I	5.6	60	(3)	(3)	(3)	(3)	(2)	(2)	(2)	60,000
	II	13	56	(3)	(3)	(3)	(3)	700,000		250,000	950,000
	III	13	56	(3)	(3)	(3)	(3)	525,000	192,000	275,000	992,000
Appalachian region (includes parts of Alabama, Georgia, Tennessee, and Virginia).	I	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------
	II	10	54	20,000	37,000	13,000	70,000	21,000	39,000	13,000	73,000
	III	11	53	21,000	38,000	15,000	74,000	22,000	40,000	15,000	77,000
Total	I	----------	----------	(2)	(2)	(2)	5,030,000–6,530,000	(2)	(2)	(2)	6,100,000–7,600,000
	II	----------	----------	53,801,000		5,713,000	59,514,000	59,898,000		5,963,000	65,861,000
	III	----------	----------	97,579,000		10,265,000	107,844,000	108,087,000		10,540,000	118,627,000

[1] Specifications: I. Prewar: Not more than 7 percent of SiO_2; not more than 3 percent FeO.
II. War Production Board specifications: Not more than 15 percent of SiO_2, not more than 6 percent of FeO, not less than 40 percent of Al_2O_3, and not less than 32 percent of "available alumina" (see text).
III. Same as II but with no restriction on iron content in any form. The tonnage listed under each specification is cumulative; that is, grade II includes grade I, and grade III includes grade I and II.

[2] Data not available for making separate estimates.

[3] Reserves in this area in deposits 8 or more feet thick cannot be estimated separately.

TABLE 6.—*Recoverable bauxite reserves of the United States as of 1944, by States or regions*

[In dry long tons (mined and dried basis)]

State or region	Grade of ore [1]	Price per long ton, dried bauxite equivalent [2]	Recoverable reserves in deposits 8 or more feet thick				Recoverable reserves in deposits 5 or more feet thick			
			Measured	Indicated	Inferred	Total	Measured	Indicated	Inferred	Total
Arkansas	I	$6.50 to $7.50	(3)	(3)	(3)	3,390,000–4,150,000	(3)	(3)	(3)	4,680,000–5,850,000
	II	$4.50 to $5.50	36,077,000		3,110,000	39,187,000	39,519,000		3,110,000	42,629,000
	III	$3.25 to $4.25	57,892,000	7,702,000	5,655,000	71,249,000	63,232,000	8,622,000	5,655,000	77,509,000
East Gulf Coastal Plain:										
Alabama	I	$6.50 to $7.50	(3)	(3)	(3)	22,000	(3)	(3)	(3)	30,000
	II	$4.50 to $5.50	222,000		148,000	370,000	259,000		148,000	407,000
	III	$4.50 to $5.50	259,000		185,000	444,000	311,000		185,000	496,000
Georgia	I	$6.50 to $7.50	(4)	(4)	(4)	(4)	(3)	(3)	(3)	44,000
	II	$4.50 to $5.50	(4)	(4)	(4)	(4)	518,000		185,000	703,000
	III	$4.50 to $5.50	(4)	(4)	(4)	(4)	388,000	143,000	202,000	733,000
Appalachian region (includes parts of Alabama, Georgia, Tennessee, and Virginia).	I	----------	None	None	None	None	None	None	None	None
	II	$5.00 to $6.00	15,000	27,000	10,000	52,000	15,000	29,000	10,000	54,000
	III	$4.50 to $5.50	16,000	28,000	11,000	55,000	16,000	30,000	11,000	57,000
Total	I	----------	(3)	(3)	(3)	3,412,000–4,172,000	(3)	(3)	(3)	4,754,000–5,924,000
	II	----------	36,341,000		3,268,000	39,609,000	40,340,000		3,453,000	43,793,000
	III	----------	65,897,000		5,851,000	71,748,000	72,742,000		6,053,000	78,795,000

1 For specifications, see table 5, footnote 1.
2 All prices based on Metals Reserve price schedule of September 1943.
3 Data not available for making separate estimates.
4 Reserves in this area recoverable from deposits 8 or more feet thick cannot be estimated separately

Bismuth

By W. S. Burbank,[34] Allan F. Matthews,[35] and John B. Zadra [35]

Before World War II, most of the bismuth supply was consumed in pharmaceuticals, but during the war bismuth alloys attained equal importance. These alloys melt at low temperatures, and their volume expands or remains constant upon solidification from melts. These properties make the alloys especially desirable for certain uses, such as in pattern metals, and fuses in fire sprinklers. There are no effective substitutes for the major uses of bismuth.

Production of bismuth was begun in the United States in 1906 and since then has supplied most of the domestic requirements, although the output is derived partly from imported lead bullion. Data on domestic production are not available for publication, but domestic consumption in 1943–45 was 1½ to 2 million pounds annually. Exports and recovery of bismuth from scrap are both negligible. The New York price of bismuth metal, which follows closely the London quotation, has varied between 85 cents a pound in 1932–33 and $4 a pound in 1915–16. It has remained steady at $1.25 a pound since 1939. The tariff on refined bismuth metal was reduced from 7½ to 3¾ percent ad valorem in July 1942, as a result of the reciprocal trade treaty negotiated with Peru.

Bismuth is obtained from two principal sources: (1) Metallurgical byproducts containing bismuth that are obtained from ores mined and treated primarily for the recovery of other metals; and (2) ores mined and treated chiefly for their content of bismuth and one or two other commonly associated metals, such as tin and tungsten. Only a few deposits are mined for bismuth alone. The domestic supply is obtained as a refinery byproduct in the treatment of domestic and foreign lead bullion and nonferrous ores, mainly lead, silver, copper, and gold. The bismuth content of these ores is concentrated in certain metallurgical products, chiefly bismuth-lead bullion, from which bismuth is recovered in the refining process. The three major domestic producers are the American Smelting & Refining Co., at Omaha, Nebr.; the Anaconda Copper Mining Co., at Perth Amboy, N. J.; and the United States Smelting, Refining & Mining Co., at East Chicago, Ind.

The principal foreign sources, in order of their importance, are the copper, lead, and silver deposits of the Cerro de Pasco district, Peru; the lead deposits of Mexico; and the tin and tungsten deposits of Bolivia. A large tungsten mine in the Province of Kangwon, southern Korea, in operation during the last year and a half of World War II, had a byproduct yield of bismuth intermediate between that of Peru and Mexico. Minor supplies come from Argentina, Chile, Brazil, and Canada. Long-accumulated Canadian stocks of bismuth-bearing residues from refineries were treated during World War II to help meet needs of the United Nations, but these sources were quickly exhausted under such extraordinary demands.

The principal domestic sources are the lead-silver ores of Utah and Colorado and the copper, lead, and zinc ores of Montana, Utah, Nevada, Arizona, Idaho, and New Mexico. Some of the gold ores of Idaho, Montana, Nevada, Alaska, Colorado, and other States contain bismuth, but only a part of it is recovered. In addition to these sources, bismuth occurs in minor quantities in many different kinds of mineral deposits from which it is not ordinarily recovered. Some deposits containing from a few hundredths of 1 percent to several percent of recoverable bismuth do not constitute economic reserves of bismuth minerals, either because of the sporadic distribution of the bismuth minerals and the low grade of the deposits or because of the lack of valuable associated minerals. The aggregate reserve of bismuth in all deposits of this nature is probably significant, but a considerable advance in technology or in the demand for, and price of, bismuth would be required to make its recovery economic.

Reserves

The reserves of bismuth in the United States that are available under present economic and technologic conditions can be roughly estimated from the average production life of the principal classes of deposits from which it is now recovered. Improvements in efficiency of recovery would increase the quantity of available bismuth somewhat, but not the life of the reserves, since the output of bismuth is controlled by demands for its companion metals. Based upon present recovery

[34] Geological Survey.
[35] Bureau of Mines.

and estimates of commercial base-metal reserves, the reserves of available bismuth metal are considered to be about 30,000,000 to 50,000,000 pounds. Material available under improved economic and technologic conditions probably exceeds those quantities. The largest sources of such material are those gold veins from which bismuth is not recovered at present and submarginal base-metal deposits containing bismuth.

Prewar normal yield of bismuth can be increased by more complete recovery of bismuth from lead by refining all bismuth residues and by special handling of high-bismuth ores now heavily penalized or rejected by smelters. Some of these sources, however, cannot be made available under present economic and technologic conditions. On the other hand, unless newly developed peacetime uses attain an unexpectedly high level, the domestic and available foreign sources appear adequate to meet United States demands for many decades.

Cadmium

By E. F. Fitzhugh, Jr.,[36] Edwin T. McKnight,[37] and T. P. Wootton[36]

Cadmium occurs as a minor constituent in the zinc minerals of zinc and lead ores. It is recovered as a byproduct from the flue dusts of lead blast furnaces and of zinc-blende roasting furnaces, from zinc dust collected in the early stages of distillation in zinc retorts, and from the sludges of electrolytic zinc plants. Nearly all such plants in the United States are equipped with cadmium recovery units; and under present technologic practice no appreciable increase in production can be obtained, except for short periods when it might be possible and advantageous to select for treatment zinc concentrates known to be relatively rich in cadmium. The cadmium derived from domestic sources is roughly proportional to domestic zinc production.

Protective electroplating of steel parts for airplanes, ordnance, automobiles, ships, and electrical and communications equipment comprises the major normal use of cadmium. Yellow and red pigments, bearings, solders, copper alloys, and fuse metal are other applications. A recent development is the use of cadmium barriers to control atomic fission. With some loss in efficiency, zinc can replace cadmium in most electroplating. In making pigments, uranium and chromium can be substituted for cadmium yellow, and gold for cadmium red.

Production of metallic cadmium in the United States was begun in 1906 and expanded to 8½ million pounds in 1944. The total output in 1906–44 was 80 million pounds. Domestic production of cadmium includes not only the cadmium derived from domestic zinc and lead ores but also that associated with virtually all the imported zinc and with a large part of the imported lead. Although only a small percentage of the imported lead is smelted in this country, a large importation of flue dust is made from Mexican lead smelters, which furnish a large percentage of our foreign lead. Imports of flue dust in 1937–44 had an average cadmium content of 1,800,000 pounds annually, about 95 percent of which is recoverable and is reported under domestic production. Of the 8½ million pounds of new cadmium produced in 1943, it is estimated that 51 percent was of domestic origin and 49 percent was foreign. Most of the foreign material comes from Mexico. Imports of metal ranged from zero to 25,000 pounds annually from 1903 to 1927, and from zero to 830,000 pounds annually from 1928 to 1944; imports in the latter period averaged 173,000 pounds annually. Production, imports, exports, and prices for each year since 1908 are shown in the accompanying figure 11. Some 200,000 to 400,000 pounds of cadium have been recovered from scrap annually in recent years. From 1910 to 1944, cadmium-metal quotations have ranged from $0.55 to $1.75 a pound; the base price from 1942 to 1944 was $0.90 a pound. World production of cadmium was 1,000,000 pounds in 1925, 5,000,000 pounds in 1934, and 11,000,000 pounds in 1940.

Reserves

As all classes of domestic zinc ores should yield zinc equivalent to 650,000 tons per year for 26 years (see Zinc section), a corresponding production of 3,750,000 pounds of cadmium per year for a like period is indicated. This is a rough approximation, projected largely from 1943 data. The ratio of cadmium to zinc produced will vary somewhat from year to year as different districts with ores

[36] Bureau of Mines.
[37] Geological Survey.

of varying cadmium content contribute to the year's zinc production. Although there is considerable variation from mine to mine, as a whole the ores of the Western and Central States carry more cadmium in proportion to zinc than do the eastern ores. Furthermore, should high-grade zinc displace greater quantities of Prime Western grade in the metal markets, the ratio of cadmium to zinc produced would increase somewhat.

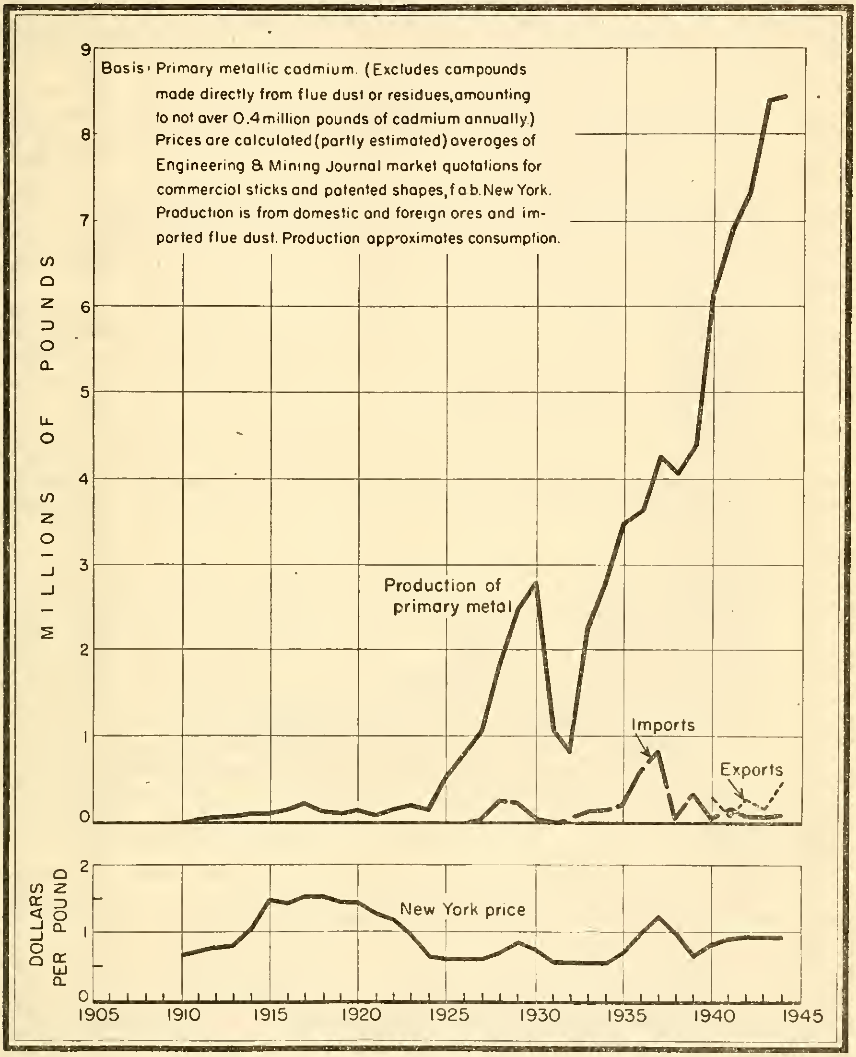

FIGURE 11.—Production and foreign trade of primary metallic cadmium in the United States, 1905–44, and New York price, 1910–44.

Assuming no major changes in the use pattern of zinc, recoverable cadmium in measured, indicated, and inferred domestic zinc ores of all economic grades is estimated at about 100,000,000 pounds, of which approximately two-thirds should be available under economic conditions comparable to those prevailing before World War II.

CHROMITE

By Albin C. Johnson,[38] C. E. Nighman,[38] and Joe Webb Peoples [39]

Chromite is a mineral containing variable amounts of chromium, iron, and aluminum. The chromium content, the ratio of chromium to iron in the ore or concentrates, the amount of non-chromium-bearing material in the chromite ore, and the physical character of the ore concentrate are the chief factors determining the grade and use of the material. Three grades of chromite corresponding to the three major uses are distinguished:

1. *Metallurgical grade.*—Prewar specifications for metallurgical ore require a minimum chromic oxide content (Cr_2O_3) of 49 percent, a chromium : iron ratio of 3 : 1 or more, and the ore be in a lumpy form. During World War II ore with a chromium : iron ratio of 2.5 : 1 was accepted, and concentrates and fines were accepted to a limited extent.

2. *Refractory grade.*—The acceptance of chromite ore as refractory grade is based less on general specifications than on actual test of usability, and the standards of the various users differ. In general, refractory ore should contain 57 percent or more of combined Al_2O_3 (alumina) and Cr_2O_3, and not more than 5 percent of silica and be in a hard, lumpy form.

3. *Chemical grade.*—There are no fixed limits for chemical-grade ore except those imposed by price and the effect of grade on plant capacity. In contrast to metallurgical and refractory ore, however, concentrates and fines are preferred, and low chromium : iron ratio is not harmful, provided the chromium content is high. The silica content should be low.

Although the grades were named for the major uses, some interchange of grade is possible. An appreciable quantity of chemical ore has been used for metallurgical purposes, metallurgical concentrates and fines have been used for chemical purposes, and metallurgical lump has been used for refractory purposes. In 1944, of the total consumption in the United States, 54 percent was for metallurgical use, 31 percent for refractory use, and 15 percent for chemical use.

The steel industry takes the greater part of the chromite used in this country; the largest amount is consumed in making ferrochromium for use in the manufacture of stainless and other alloy steels. Some ore is used directly in the steel bath. Chromium increases hardness and shock resistance and imparts high tensile strength and ductility to steel. Other metallurgical uses include the manufacture of certain cast-iron and nonferrous alloys. The addition of chromium to cast iron reduces the grain size greatly, increases its resistance to wear and corrosion, and reduces oxidation at high temperatures. Refractory grade, as crude ore, as a plastic cement, and as brick, is used largely in steelmaking furnaces. Chemical ore is used for the production of chromium chemicals which are used in tanning leather, pigments, chromium plating, and other applications.

There is no completely satisfactory substitute for chromium in stainless and other alloy steels, but some of the chromium can be replaced by molybdenum and manganese.

Some chromium is recovered from scrap, the major problem being segregation of chromium-bearing scrap from other scrap so that it can be used in the manufacture of chromium steels, and important advances have been made in this respect.

During both war and peace the production of domestic chromite of all grades has been far less than was needed, and no refractory ore has been produced in this country. Demands for metallurgical ore are met by imports from Rhodesia, Turkey, the Soviet Union, and New Caledonia, and for refractory ore from Cuba and, before the war, from the Philippines and Greece. Reserves of refractory ore in Cuba are adequate to take care of the needs of the United States for several years.

The production of domestic chromite has been negligible, except during three periods—1828–80, 1916–18, and 1941–44. During the first period, 250,000 long tons of high-grade lump ore was produced in Pennsylvania and Maryland, chiefly from two mines that are now exhausted. During the second period 172,881 tons of ore, chiefly lump, was produced in California and Oregon to meet the demands of World War I. During the recent war, wartime price and Government aid in the form of roads, plants, etc., resulted in a total output of 297,000 tons by

[38] Bureau of Mines.
[39] Geological Survey.

January 1, 1945, chiefly in the form of concentrates. California was the largest producer, with a narrow margin over Montana. Oregon ranked third. Concentrates of 38 to 43 percent Cr_2O_3, with a 1.4:1.7 chromium: iron ratio, which are not normally usable, make up 50 percent of the World War II total. The total production of the United States to date approximates the domestic consumption in only 1 year—1943. Figure 12 shows the production, consumption, and price of chromite in the United States from 1910 to 1944.

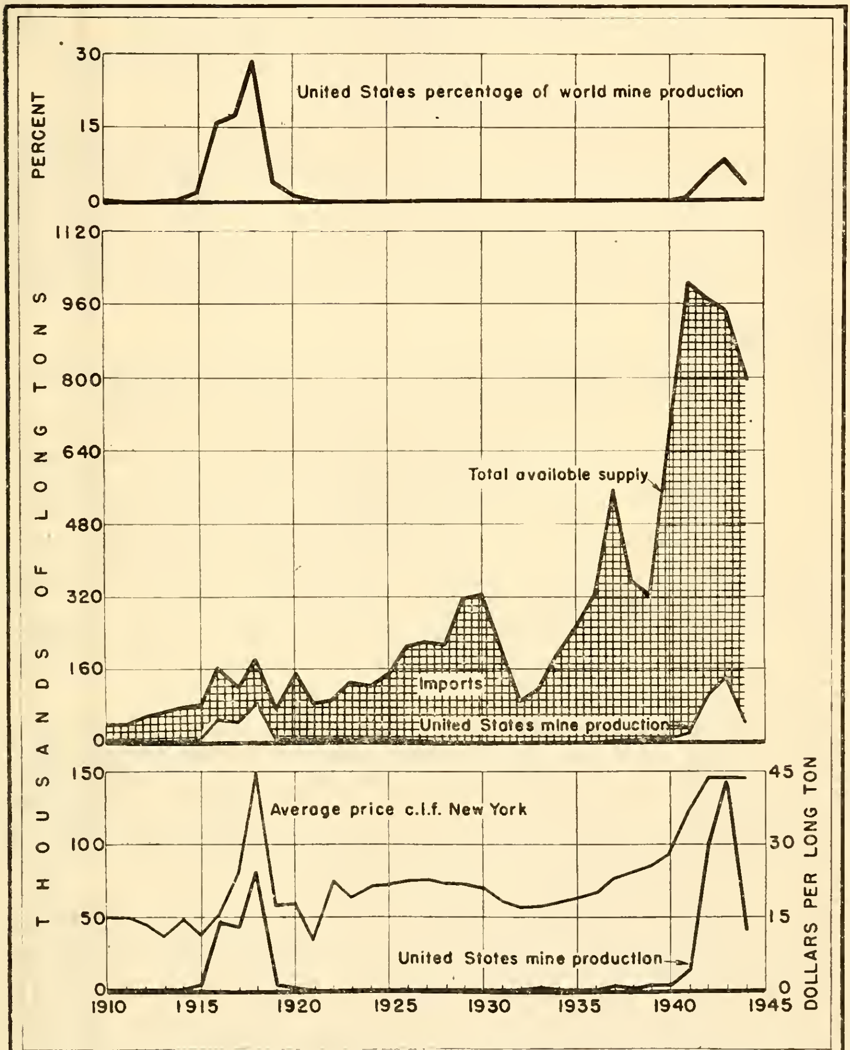

FIGURE 12.—Trends in production and available supply of all grades of chromite, and in the price of imported chromite in the United States. 1910–44.

Reserves

The only known reserves of metallurgical lump ore in the United States occur in California, Oregon, and Alaska. The total does not exceed 25,000 tons. There are no known reserves of strictly refractory-grade ore, though some domestic ore doubtless could be used for refractory purposes.

Table 7 shows the unmined reserves of all grades of ore in place in the United States, by States, as estimated in 1943, and table 8 the reserves that would be

available under various economic and technologic conditions. Chart V illustrates the distribution of production and reserves of chromite, by States and districts.

TABLE 7.—*Estimated chromite reserves of the United States in the ground as of 1943, by States*

[In long tons of Cr_2O_3 content]

State	Range of chromium: iron ratio [1]		Measured	Indicated	Inferred	Total
	From—	To—				
Montana	1.4:1	1.7:1	415,000	590,000	500,000	1,505,000
Oregon	1.5:1	3.0:1	154,000	84,000	55,000	293,000
Alaska	2.5:1	3.5:1		71,000	26,000	97,000
California	1.5:1	3.3:1		19,000	31,000	50,000
Wyoming	0.6:1	1.2:1		38,000		38,000
Washington	2.3:1	3.0:1		5,000	19,000	24,000
Other					5,000	5,000
Total			569,000	807,000	636,000	[2] 2,000,000

[1] In cleaned chromite.
[2] Round numbers.

TABLE 8.—*Availability of chromite reserves of the United States under various economic and technologic conditions*

Conditions	Minimum Cr:Fe ratio	Minimum Cr_2O_3 content (percent)	Estimated reserve (long tons of Cr_2O_3)			
			Measured	Indicated	Inferred	Total [1]
Average peacetime	3:1	48	None	1,000	9,000	10,000
Similar to 1944	2:1	35	7,500	70,000	42,000	120,000
Future, either (*a*) an emergency worse than recent war or (*b*) improved technology	1:1	(2)	(2)	(2)	(2)	2,000,000

[1] Round numbers.
[2] Not susceptible to detailed estimation.

The reserves available under normal peacetime conditions are negligible. Those available under 1944 conditions, including the price schedule and specifications established by the Metals Reserve Company, or under conditions similar to those of 1944, total 120,000 tons of Cr_2O_3. Even though the prices specified by the Metals Reserve Company are higher than the average peacetime price and the specifications of usable material less strict, the available reserves are still only about 30 percent of 1 year's domestic consumption at the 1944 rate, and less than 1 year's consumption at the normal rate of use.

For estimating the reserves available under future conditions, it has been assumed that either an emergency greater than that of World War II would arise or that technology would be greatly improved and that, under such conditions, material with a chromium : iron ratio as low as 1 : 1 would be usable. No deposits are included that contain less than 5,000 long tons of Cr_2O_3. The lode deposits in Montana and the Oregon beach sands constitute nearly 85 percent of the total; the chances of increasing reserves in these two areas are greater than elsewhere, so that in future this proportion is likely to be increased. For the Oregon beach sands, estimated to contain 260,000 tons of Cr_2O_3, a cut-off of 3 percent Cr_2O_3 content in the crude material was used; for the Montana deposits, estimated to contain 1,505,000 tons of Cr_2O_3, a cut-off of 15 percent of Cr_2O_3 in layers 3 feet or more thick was used. The estimates of inferred ore are believed to be conservative.

The greater part of domestic reserves can be utilized for metallurgical purposes only by accepting substandard material or by chemical or electrolytic treatment of ore or concentrate; the chromite in most of the deposits has too low a chromium : iron ratio to allow concentration by mechanical means to a standard usable product. Within the next decade, the recovery of chromium metal by electrolytic methods may make these reserves commercial.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY AND BUREAU OF MINES

CHROMITE

MINERAL RESOURCES OF THE UNITED STATES

CHART V.—Distribution of estimated reserves of chromite (all grades) in the United States and Alaska as of 1943 and total production through 1943, by districts.

Coal

By John W. Buch,[40] Thomas A. Hendricks,[41] and Albert L. Toenges[40]

Coal is important principally as a source of energy, and this appraisal of the coal resources of the United States considers coal in that light. Normally the United States has a net export trade in coal which is relatively small compared with the total annual output. Figure 13 shows the production, consumption, net exports, weighted average price of coal produced in the United States from 1900 to 1944, and relationship of domestic output to world production.

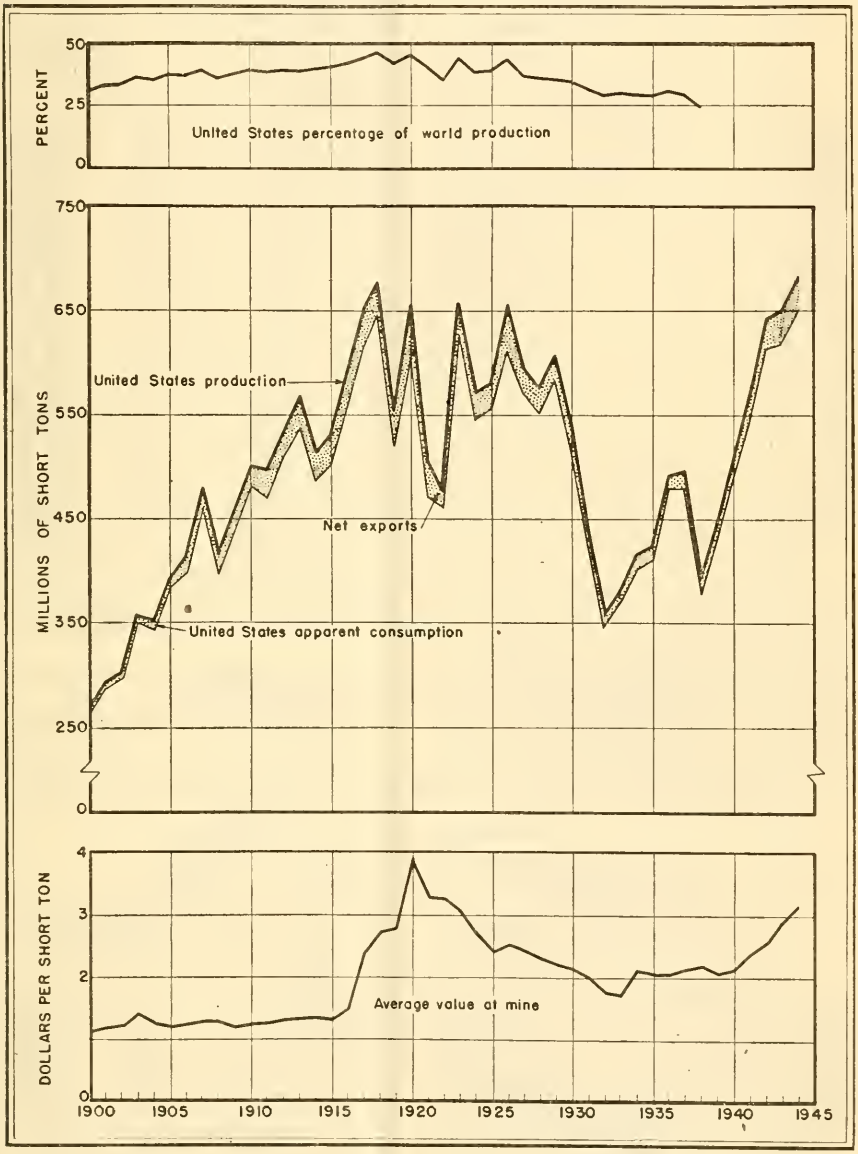

FIGURE 13.—Trends in production, consumption, and price of coal in the United States, 1900–44. Data cover all coals, including anthracite and bituminous coal, and lignite. Value at mine is a weighted average.

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[40] Bureau of Mines.
[41] Geological Survey.

The United States has about half the known coal reserves of the world. The distribution of domestic reserves is shown in tables 9 to 12 and on the map, chart VI.

TABLE 9.—*Bituminous-coal resources of the United States as of January 1944, by States*

[In thousands of net tons]

[Compiled by Thomas A. Hendricks]

State	Estimated original reserve	Reserve depleted through 1943			Remaining reserve, January 1944 [2]
		Produced	Lost in mining [1]	Total	
Alabama	67, 570, 000	719, 895	382, 552	1, 102, 447	66, 468, 000
Arkansas	1, 396, 000	73, 292	36, 947	112, 239	1, 284, 000
Colorado	213, 071, 000	314, 653	167, 207	481, 660	212, 569, 000
Georgia	933, 000	11, 127	5, 913	17, 040	916, 000
Illinois	201, 400, 000	2, 728, 387	1, 449, 865	4, 178, 252	197, 222, 000
Indiana	53, 051, 000	845, 480	449, 288	1, 294, 768	51, 756, 000
Iowa	29, 160, 000	326, 936	173, 734	500, 670	28, 659, 000
Kansas	30, 000, 000	251, 453	133, 622	385, 075	29, 615, 000
Kentucky	123, 327, 000	1, 514, 785	804, 957	2, 319, 742	121, 007, 000
Maryland	8, 043, 000	249, 701	132, 691	382, 392	7, 661, 000
Michigan	2, 000, 000	46, 224	24, 563	70, 787	1, 929, 000
Missouri	84, 000, 000	232, 573	123, 589	356, 162	83, 644, 000
Montana	2, 655, 000	30, 238	16, 068	46, 306	2, 609, 000
New Mexico	18, 925, 000	81, 302	43, 204	124, 506	18, 800, 000
North Carolina	68, 000	1, 220	648	1, 868	66, 000
Ohio	93, 967, 000	1, 496, 255	795, 110	2, 291, 365	91, 676, 000
Oklahoma	54, 951, 000	139, 407	74, 081	213, 488	54, 738, 000
Pennsylvania	75, 093, 459	[3] 6, 593, 885	3, 503, 991	10, 097, 876	64, 996, 000
Tennessee	25, 665, 000	288, 872	153, 507	442, 379	25, 223, 000
Texas	8, 000, 000	10, 548	5, 605	16, 153	7, 984, 000
Utah	88, 184, 000	154, 252	81, 970	236, 222	67, 948, 000
Virginia	21, 149, 000	439, 968	233, 799	673, 767	20, 475, 000
Washington	11, 413, 000	117, 440	62, 408	179, 848	11, 233, 000
West Virginia	116, 705, 415	[4] 4, 034, 599	2, 143, 986	6, 178, 585	110, 527, 000
Wyoming	30, 563, 000	192, 189	102, 129	294, 318	30, 269, 000
Other States	697, 000	3, 277	1, 741	5, 018	692, 000
Total [5]	1, 361, 986, 874	20, 897, 958	11, 105, 175	32, 003, 133	1, 329, 984, 000

[1] Coal lost computed as 34.7 percent of coal in ground or 53.14 percent of coal produced. After Rice, G. S., and Paul, J. W., Amount of Nature of Losses in Mining Bituminous Coal in Eastern United States: Report of U. S. Coal Commission, 1923, pt. 3, pp. 1841, 1876.
[2] Rounded to nearest million.
[3] Reese, John F., and Sisler, James D., Bituminous Coal Fields of Pennsylvania—Coal Reserves. Pennsylvania Geol. and Topog. Survey, Bull. 46, pt. 3, 1928, p. 7.
[4] West Virginia Geological Survey, vol. 10, 1934, p. 314.
[5] Discrepancy of 2,000,000 tons in total remaining reserves, January 1944, between sum of vertical and horizontal State totals due to method of rounding figures.

TABLE 10.—*Subbituminous-coal resources of the United States as of January 1944, by States*

[In thousands of net tons]

[Compiled by Thomas A. Hendricks]

State	Estimated original reserve	Reserve depleted through 1943			Remaining reserve, January 1944 [2]
		Produced	Lost in mining [1]	Total	
Colorado	104, 175, 000	92, 200	48, 995	141, 195	104, 034, 000
Montana	62, 985, 000	113, 230	60, 170	173, 400	62, 812, 000
New Mexico	1, 906, 000	30, 684	15, 978	46, 662	1, 859, 000
Utah	5, 156, 000	2, 666	1, 417	4, 083	5, 152, 000
Washington	52, 442, 000	18, 426	9, 792	28, 218	52, 414, 000
Wyoming	590, 160, 000	122, 673	65, 189	187, 862	589, 972, 000
Other States [3]	1, 757, 000	2, 488	1, 022	3, 810	1, 753, 000
Total	818, 581, 000	382, 367	202, 863	585, 230	817, 996, 000

[1] Coal lost computed as 34.7 percent of coal in ground or 53.14 percent of coal produced. After Rice, G. S., and Paul, J. W., Amount and Nature of Losses in Mining Bituminous Coal in Eastern United States: Report of U. S. Coal Commission, 1923, pt. 3, pp. 1841–1876.
[2] Rounded to nearest million.
[3] Includes Arizona, California, Idaho, and Oregon.

COAL

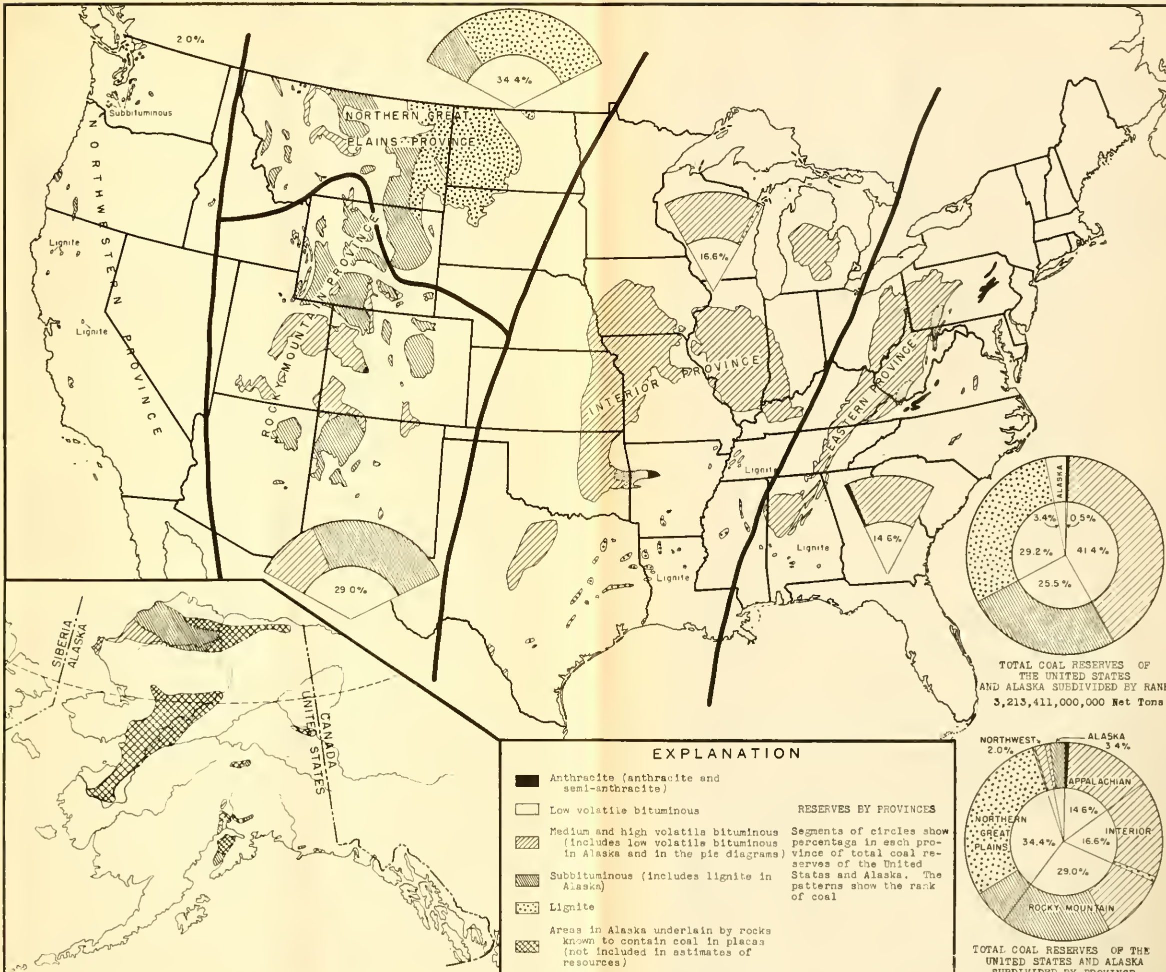

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CHART VI.—Distribution of coal resources of the United States and Alaska as of 1944, by types of coal and by provinces.

TABLE 11.—*Lignite resources of the United States as of January 1944, by States*

[Compiled by William G. Pierce]

[In thousands of net tons]

State	Estimated original reserve	Reserve depleted through 1943			Remaining reserve, January 1944 [2]
		Produced	Lost in mining [1]	Total	
Arkansas	90,000				90,000
Montana	315,474,000	1,033	310	1,343	315,473,000
North Dakota	600,000,000	51,385	15,415	66,800	599,933,000
South Dakota	1,020,000	679	204	883	1,019,000
Texas	23,000,000	50,183	15,055	65,238	22,935,000
Other States	10,000				10,000
Total	939,594,000	103,280	30,984	134,264	939,460,000

[1] Due to high percentage of lignite mined by stripping, losses are estimated as only 30 percent of coal produced as compared with usual average of 34.7 percent for other coals.
[2] Rounded to nearest million.

TABLE 12.—*Anthracite resources of the United States as of January 1944, by States*

[Compiled by Paul Averitt]

[In thousands of net tons]

State	Estimated original reserve	Reserve depleted through 1943			Remaining reserve, January 1944 [2]
		Produced	Lost in mining [1]	Total	
Arkansas	230,000	6,259	3,326	9,585	220,000
Colorado	100,000	5,634	2,994	8,628	91,000
New Mexico	[3] 3,000	1,033	549	1,582	1,000
Pennsylvania	[4] 23,263,426	4,595,704	3,763,823	8,359,527	14,904,000
Virginia	500,000	8,817	4,685	13,502	486,000
Washington	23,000				23,000
Total [5]	24,119,426	4,617,447	3,775,377	8,392,824	15,727,000

[1] Losses taken as same as for bituminous coal except for Pennsylvania, where losses were estimated to equal production through 1913 and to be 61.29 percent of production since 1913 (see Ashmead, D. C., Anthracite Losses and Reserves in Pennsylvania; Pennsylvania Geol. and Topog. Survey Bull. M8, 1926, p. 70).
[2] Rounded to nearest million.
[3] Computation based on work by Lee, W. T., The Cerrilos Coal Field, Santa Fe County, N. Mex.: U. S. Geol. Survey Bull. 531, pp. 285–312, 1921.
[4] Ashmead, D. C., work cited in footnote 1, p. 67.
[5] Discrepancy of 2,000,000 tons in total remaining reserves, January 1944, between sum of vertical and horizontal State totals due to method of rounding figures.

The annual supply of energy in the United States per million of population, from all mineral fuels and water power, rose from 71 trillion B. t. u. in 1889 to 194 trillion B. t. u. in 1940, nearly a threefold increase as compared with only a twofold increase in population over the same period. (See table 13.) This increase in consumption of energy resulted from a number of factors, including (1) industrial expansion; (2) a rising standard of living; and (3) developments to accommodate the increased population. Consumption would have been still greater had not utilization of the various forms of energy been more efficient. The National Resources Planning Board has estimated that the population of the United States will reach a maximum in 1980 of about 158 million. At the 1940 rate of supply of energy, a population of that size will need 36,652 trillion B. t. u. annually, as compared to the 1940 supply of 25,587 trillion B. t. u.

Of the energy made available in 1940, bituminous coal and lignite supplied 47.2 percent, Pennsylvania anthracite 5.5 percent, petroleum 32.7 percent, natural gas 11.2 percent, and water power 3.4 percent. In future years, however, the solid fuels may be called upon to provide a larger proportion of the energy used as supplies of natural gas and petroleum dwindle. Liquid fuels not available from petroleum and oil shale will be made principally from coal. Subbituminous coals and lignites have been found suitable for liquefaction and could be ex-

ploited in preference to high-rank bituminous coals,[42] which are essential for domestic, metallurgical, and special industrial uses. A large annual tonnage of coal and lignite suitable for liquefaction could be mined from the northern Great Plains and Rocky Mountain provinces and possibly also from the southern interior province. The rate of depletion of the thicker, more accessible beds of bituminous coal has been accelerated by demands of war, and coal in thinner beds, in areas not now easily accessible, must be developed in the near future.

TABLE 13.—*Annual supply of energy from mineral fuels and water power in the United States and production of coal and lignite, 1889–1980*

Year	Total annual supply of energy (trillion B. t. u.) [1]	Million population	Annual supply of energy (trillion B. t. u. per million population)	Percent of annual supply of energy from coal and lignite [2]	Total production, anthracite, bituminous coal, and lignite (thousands of net tons)
1889	4, 385	[3] 62	71	85. 4	141, 230
1900	8, 009	[3] 76	105	88. 9	269, 684
1910	15, 572	[3] 89	175	84. 9	501, 596
1920	22, 227	[3] 106	210	78. 0	658, 265
1930	22, 738	[3] 122	186	62. 2	536, 911
1940	25, 567	[3] 132	194	52. 7	512, 256
1950	[4] 27, 742	[5] 143			
1960	[4] 29, 100	[5] 150			
1970	[4] 30, 264	[5] 156			
1980	[4] 30, 652	[5] 158			

[1] Water power at prevailing central-station equivalent, except equivalent of 7.05 pounds of coal per kilowatt-hour used for 1889; 1940 figure was 1.35 pounds per kilowatt-hour.
[2] Based on water power at prevailing central-station equivalent, with exception stated in footnote 1.
[3] Bureau of the Census.
[4] Estimate based on 1940 annual supply of 194 trillion B. t. u. per million population, extended on basis of estimated population for the respective years.
[5] National Resources Planning Board, Estimates of Future Population of the United States: August 1943.

Reserves

Reserves of bituminous coal, subbituminous coal, and lignite in place in continental United States are estimated at about 3.1 trillion tons as of January 1944, sufficient for nearly 3,400 years at a yearly rate of production approximating the maximum rate in the past—600 million tons—and with current mining losses. These reserves include the following:

	Net tons
Bituminous coal	1, 329, 984, 000, 000
Subbituminous coal	817, 996, 000, 000
Lignite	939, 460, 000, 000
Total	3, 087, 440, 000, 000

Reserves of anthracite in place are estimated at about 16 billion tons, adequate for about 160 years at the current annual output of about 60 million tons and with current mining losses. The reserves of coal of various ranks were determined by estimating the original quantities present in the ground and deducting from them the total production and losses in mining through 1943. Except as specified in the accompanying tables, the original quantities were taken from an estimate prepared by M. R. Campbell in 1928 and used later by T. A. Hendricks.[43]

Details of these estimates are presented in tables 9 to 12. Although tables 9 and 11 show large reserves of both bituminous coal and lignite in Texas, extensive exploration will be necessary in that State to prove the extent and quality of individual beds; except for this qualification, all the reserves shown in the tables are reasonably accurate in view of the order of magnitude.

Because of the ever-increasing improvement in coking techniques, including the blending of different coals for making coke, the reserves of coking coal are difficult to estimate. For the region east of the Rocky Mountains, increased ap-

[42] Coal having a moist, mineral-matter-free heating value of 14,000 B. t. u. per pound or more and having less than 86 percent, dry, mineral-matter-free fixed carbon. (This includev low-, medium-, and high-volatile A bituminous coals.)
[43] Hendricks, T. A., Coal Reserves, Energy Resources, and National Policy: 76th Cong., 1st sess., H. Doc. 160, 1939, pp. 281–285.

plication of processes now in use, such as washing, blending, and separation of noncoking fractions, could render at least 10 percent of the known bituminous reserves suitable for conversion to metallurgical coke. In the West, however, extensive research probably will be needed to establish adequate supplies of coking coal. It is noteworthy that coals suitable for conversion to coke are also excellent for steam raising and domestic use and are being mined at a relatively greater rate than noncoking coals.

Coal and lignite are present in substantial quantities at numerous places in Alaska; but as few deposits have been studied in detail, the reserves can be classified only as indicated or inferred, and the figures in table 14 are significant only as to order of magnitude. The coal in the Matanuska Valley and Nenana fields on the Alaska Railroad, from which has come most of Alaska's total production since 1885—totaling 3,375,000 tons through 1943—is known in the greatest detail. Because of high costs of mining and shipment, Alaska coals are important only for use in the Territory.

TABLE 14.—*Summary of available data on coal resources of Alaska as of January 1944, by regions*

[In thousands of net tons]

[Compiled by Clyde Wahrhaftig]

Region	Rank of coal	Accessible by present means of transportation	Within 40 miles of present means of transportation [1]	Remote from present means of transportation
1. Arctic Ocean drainage	Lignite and subbituminous			60,000,000
	Bituminous			22,000,000
2. Yukon and Kuskokwim drainage basins (exclusive of areas south of the Tanana River tributary to the Alaska Railroad and the Richardson Highway).	Lignite and subbituminous		400,000	
	Bituminous		(2)	
3. Pacific Ocean drainage and Alaska Peninsula (includes area excluded in 2).	Lignite and subbituminous	2,400,000	22,000,000	186,000
	Bituminous	450,000	1,800,000	
	Anthracite		1,000,000	
4. Southeastern Alaska	Lignite	8,000		
Total	Lignite and subbituminous	2,408,000	22,400,000	60,186,000
	Bituminous	450,000	1,800,000	22,000,000
	Anthracite		1,000,000	

[1] Includes coal accessible by present means of transportation.
[2] Present, but quantity unknown.

Total estimated coal resources in Alaska (rounded)—110,000,000.

COBALT

By W. S. Burbank,[44] H. W. Davis,[45] and Albin C. Johnson [45]

The largest use of cobalt is in stellite or stellite-type alloys, which contain 45 to 55 percent of cobalt, 30 to 35 percent of chromium, and 12 to 17 percent of tungsten; there are several variations from this composition, but all contain high percentages of cobalt. Stellite alloys are used for high-speed, heavy-duty, high-temperature cutting and die materials. The second largest use of cobalt is in magnets and magnet steels. Other important applications are in high-speed steels and other cutting-tool materials, valve steel, welding rod, and carbide-type alloys. Smaller quantities of cobalt are employed in the ceramic industry, in the preparation of driers, in electroplating, as a catalyst, and for a variety of minor uses. Cobalt is an important constituent in the alloys used in jet-propulsion gas turbine and turbo-superchargers. The demand for these products may greatly increase the demand for cobalt in the future. There are no satisfactory substitutes for the metal in its principal uses.

Data on the quantity of cobalt actually consumed annually in the United States before 1941 are not available; but, as demand was supplied almost wholly from

[44] Geological Survey.
[45] Bureau of Mines.

foreign sources, consumption is roughly indicated by the imports, which comprise metallic cobalt, cobalt oxide, cobalt sulfate, and other salts of the metal, the estimated cobalt content of which ran from 155,000 pounds in 1921 to 2,660,000 pounds in 1939. Industrial consumption was about 3 million pounds in 1941 but advanced to 4.6 million pounds in 1944.

Since 1940 there has been a relatively small but increasing production of byproduct cobalt from the iron ore mined at Cornwall, Pa. An insignificant quantity of cobalt is recovered as a byproduct of talc production in Vermont, and a small amount is recovered in an electrolytic zinc plant in the Northwest. Domestic production, as measured by shipments, was as follows: 127,000 pounds in 1940, 521,627 pounds in 1941, 661,657 pounds in 1942, and 763,772 pounds in 1943. In 1944 the St. Louis Smelting & Refining Co. revived production of a nickel-cobalt concentrate as a byproduct from the lead-copper-nickel deposits at Fredericktown, Mo.; production of cobalt-nickel concentrate was suspended in September 1945. The copper-cobalt deposits of the Blackbird district, Idaho, were being developed in 1945. Numerous minor occurrences of cobalt-bearing ores are known in the Western States and in the Appalachian region.

Although cobalt production has been reported in about 14 countries, Belgian Congo, Burma, Canada, French Morocco, and Northern Rhodesia have for many years supplied the bulk of the production, which was about 5,500 to 6,000 short tons in 1942; since that time the output in Belgian Congo has increased substantially. Belgian Congo and Canada are the principal foreign sources supplying domestic demand. Belgian Congo is the largest source in the world and has supplied about 45 percent or more of world production. In 1945 Belgian Congo had made provisions for producing about 600 tons of cobalt per month. Canadian production has been declining and will continue on this general course because the deposits are considerably depleted. Normal needs for world consumption can be supplied for many years by the principal known deposits, so that the development of various minor and noncommercial resources is not likely to be commercially stimulated in the near future unless demand increases greatly.

Relatively little cobalt is exported from the United States, and figures were not separately recorded before July 1941. In 1944, however, exports totaled 480,521 pounds.

Domestic quotation on cobalt metal in 100-pound lots remained unchanged at $1.50 a pound from October 1939 to October 1943. On November 2, 1943, the Office of Price Administration established a price of $1.50 to $1.57 a pound on contract and $1.60 to $1.67 on spot sales. From August 1937 to September 1939 the price was $1.36.

Reserves

For the purposes of this report, the cobalt deposits of the United States have been divided into those that could be made available under economic and technologic conditions similar to those existing in 1943 (class 1) and those that may become available under increased prices and a considerable advance in technology (class 2). (See table 15.) Class 1 includes primarily the deposits at Cornwall, Pa.; Fredericktown, Mo.; and the Blackbird district, Idaho. The Cornwall ores constitute the largest class 1 reserve; they contain only about 0.05 percent of cobalt, which is intimately associated with pyrite. Concentration for the recovery of cobalt is therefore readily effected by separation of the pyrite, which contains a little less than 1.5 percent of cobalt and represents a recovery of about 65 percent of the cobalt in the ore. The complex lead-copper-nickel deposits of Fredericktown, Mo., contain about 0.3 percent of cobalt, and the copper-cobalt ores of Blackbird, Idaho, about 0.5 percent or more.

Class 2 deposits comprise mainly sulfide ores in the Appalachian region that are now of interest chiefly for their copper or sulfur and iron content. These ores contain from a few hundredths to 0.1 percent of cobalt, but data are not as yet available to permit accurate determination of the average content. The problem of recovering the cobalt by present methods of treating these ores has not been solved. Certain low-grade manganese deposits of the southern Appalachians contain small quantities of cobalt, but the technology of their treatment and cobalt recovery has received only experimental attention. Cobalt in manganese ores can be recovered in the electrolytic recovery of manganese; should production of electrolytic manganese be greatly expanded, appreciable quantities of byproduct cobalt might be produced.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY AND BUREAU OF MINES

COBALT

MINERAL RESOURCES OF THE UNITED STATES

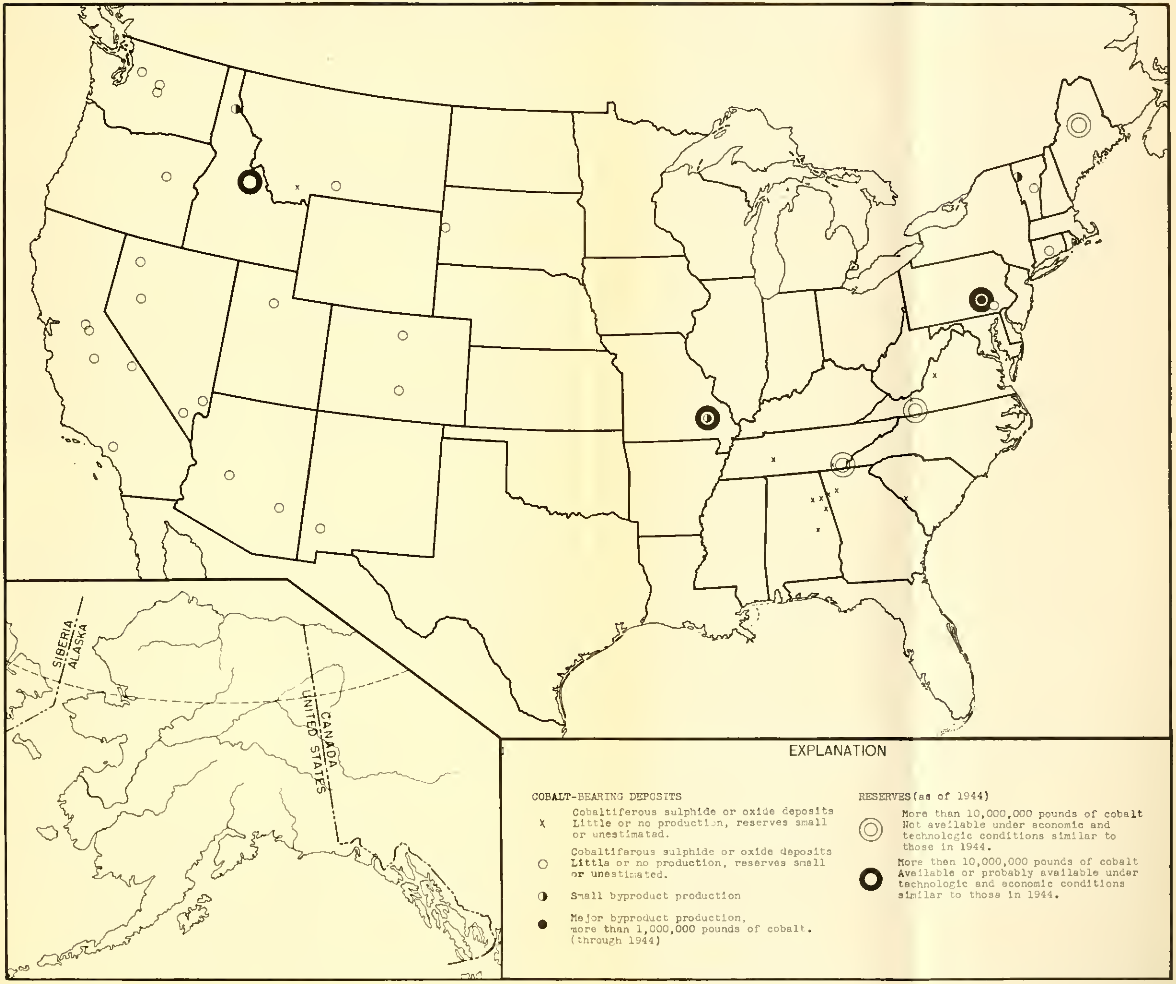

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CHART VII.—Distribution of cobalt deposits of the United States and estimated cobalt reserves as of 1944, by regions.

Chart VII shows the distribution of the cobalt resources of the United States as of 1943. The data available do not permit a break-down of measured and indicated ore, so the reserves in this category have been put under one heading.

TABLE 15.—*Estimated reserves of cobalt in the United States as of 1943*

[In short tons]

Availability	Measured and indicated		Inferred		Total	
	Crude ore	Cobalt content	Crude ore	Cobalt content	Crude ore	Cobalt content
Class 1 [1]	45,350,000	30,000	64,300,000	59,000	109,650,000	89,000
Class 2 [2]	43,000,000	32,500	125,000,000	75,000	168,000,000	107,500

[1] Reserves that could be made available under such economic and technologic conditions as in 1943.
[2] Reserves that could be made available only under some increase in price over that of 1943 and under considerable advance in technology.

The total estimated reserve available under such wartime conditions as prevailed in 1943 is 89,000 short tons, equivalent to 100 years' supply at the rate of use during the five prewar years 1935–39, and 38 years' supply at the peak war rate, if it could be produced at any such rate; however, the nature of cobalt occurrence is such that it would be produced chiefly as a byproduct, and for this reason the rate at which it could be produced would be determined largely by factors governing the output of the associated products. The rate of output in the near future, as in the past, will be governed chiefly by operations at Cornwall, Pa. The outlook for new production is very uncertain and will depend upon the outcome of mining and metalluirgical developments in the Blackbird, Idaho, and Fredericktown, Mo., areas, in both of which cobalt is associated with other metals.

COPPER

By Ralph S. Cannon, Jr.,[46] Helena M. Meyer,[47] and McHenry Mosier [47]

The reserves of available copper in the United States have declined appreciably since the early thirties, when reserves of copper ore were generally estimated to contain more than 25 million short tons of metal. Production has exceeded the discovery and development of new reserves by a considerable margin, particularly in recent years. Moreover, a tendency for uses to expand and for demand to exceed the domestic supply has become increasingly apparent since World War I, and both these trends have been accentuated by the enormous requirements of copper for the recent war. On the other hand, world resources appear adequate to supply a gradually increasing demand for some years to come.

[46] Geological Survey.
[47] Bureau of Mines.

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Figure 14 shows basic trends in the United States copper industry from 1900 to 1944.

In peacetime more than half of the copper consumed in the United States is used in the metallic form, primarily by the electrical industry in the manufacture of generators, motors, electric locomotives, switchboards, telephone and tele-

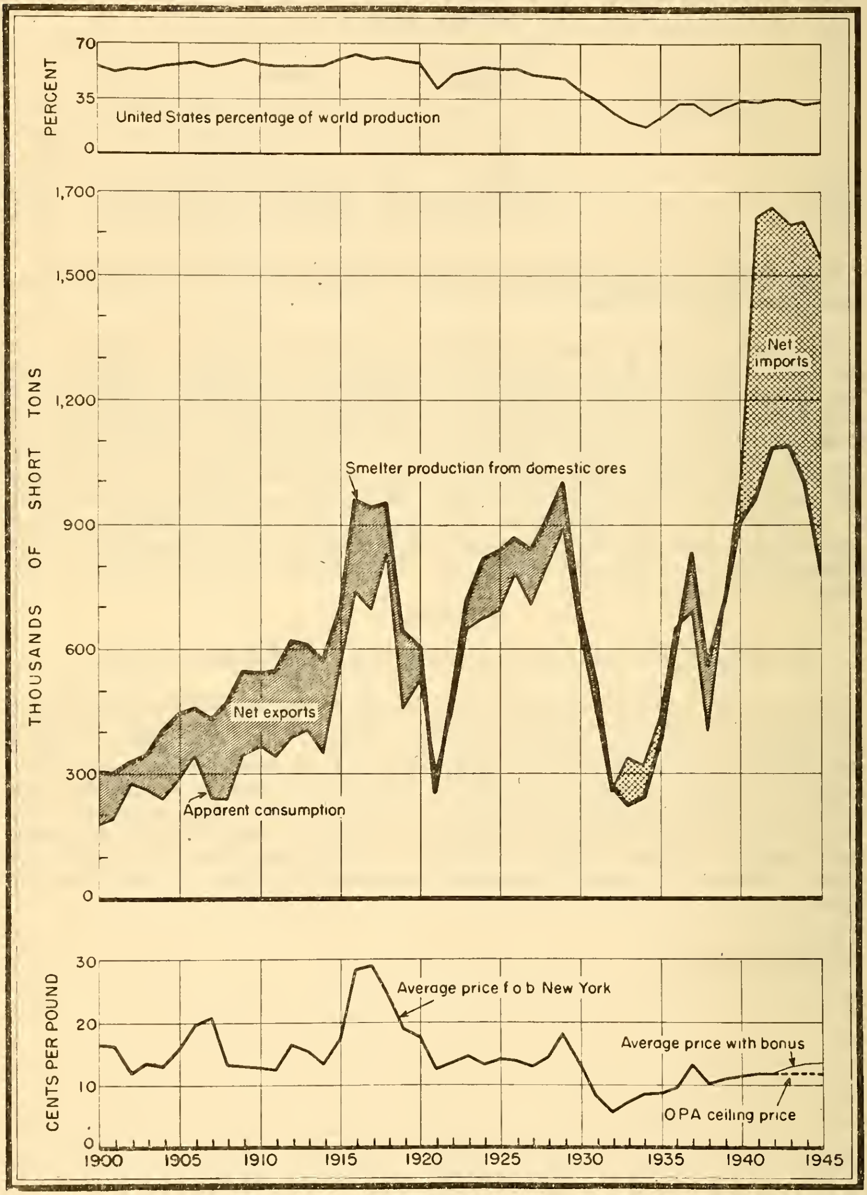

FIGURE 14.—Trends in production, consumption, and price of copper in the United States, 1900–44.

graph equipment, light and power lines, and other items. Most of the remainder is employed by the alloy industry in manufacturing brass, bronze, and other copper alloys that are used ultimately in building construction, automobile manu-

facture, ammunition, shipbuilding, and a wide variety of other purposes. Beryllium-copper is notable among new developments in copper alloys. Under war conditions, the principal use of copper is in the manufacture of munitions. Large amounts also are required for naval and other ship construction, and for the manufacture of signal equipment and ordnance. Of these uses, shipbuilding and most of the strictly military applications were sharply curtailed after the war; but most of the prewar uses of copper are being resumed at high levels, and additional new uses for copper can be anticipated.

Other materials can replace copper for certain of its uses, and under favorable conditions various metals and alloys have served as substitutes in many applications, but copper probably will not be significantly displaced by substitute materials in peacetime industry. Because of copper's unusual combination of desirable properties, a universal substitute has never been found. Its electrical and thermal conductivity are the highest of all the metals except silver, and its ductility and other physical properties permit ready fabrication for industrial and commercial uses in forms that are decorative as well as durable.

Aluminum can be employed as a substitute for copper in some electrical applications, particularly where size is not a factor, and this use of aluminum may be encouraged further by future changes in the prices of the two metals. Silver has slightly better electrical conductivity than copper, but its relative scarcity and high price preclude its substitution for copper on a large scale under usual conditions. Copper-clad steel is sheet steel or steel wire to which a covering of copper adheres as a result of heat treatment or rolling. Copper alloys may be substituted, but where high electrical conductivity is required copper itself is preferred. The "clad" products have additional tensile strength imparted by the steel but largely retain the fabricating qualities of copper and have the added resistance to corrosion imparted by the copper covering. Copper-clad steel is used for transmission of electricity in railway signal systems and for long spans on high-potential transmission lines. Zinc die-castings, magnesium, plastics, and even glass are included among the numerous other materials that can be partly substituted for copper or copper alloys.

Copper is readily reclaimed from most discarded articles made of it or its alloys, and little of the metal is lost during use because of its resistance to wear and corrosion. Copper recovered from scrap is, in effect, a substitute for newly mined copper, and the supply of scrap available probably influences the demand for newly mined copper more than all other substitutions. The relative importance of scrap copper, as well as the actual rate of recovery, increased rather steadily from 1910 to 1944. Copper is reclaimed from both new and old scrap. New scrap is waste produced during the process of fabrication. It includes trimmings from stock shapes, turnings, borings, defective castings, and refuse from melting pots and furnaces. Old scrap is "used" or obsolete copper, brass and other copper alloys salvaged from equipment, machinery, communication, power and trolley lines, and other sources. The supply of copper from new scrap varies widely in response to fluctuations in the rate of industrial activity. The recovery of copper from old scrap is comparatively uniform and is thus of greatest relative importance in depression years, such as 1933 and 1934, when it actually exceeded smelter output from domestic ores. Much more copper scrap will be reclaimed from munitions after the recent war than after World War I, and it will supplant a corresponding amount of newly mined copper unless stockpiled for future emergency use.

Chart VIII shows the distribution of recent copper production and the more important copper reserves of the United States as of January 1944.

In 1944 more than 68 percent of the copper produced came from the large, low-grade deposits, known as "porphyry coppers," in Arizona, Nevada, New Mexico, and Utah. The feasibility of exploiting a large body of low-grade ore was first demonstrated at Bingham, Utah, and the Southwest soon became the center of copper mining in the United States. However, unless new discoveries are made, the peak of production from these low-grade deposits appears to be not far distant.

About 1894 the United States began to supply more than half of the world production and consistently maintained this position until about 1930, although the first signs of decline in the relative importance of the domestic industry appeared in 1921–22. Today, even though the United States is still the leading copper-producing nation, domestic production comprises only about one-third of the

world supply. The total domestic production from 1841 through 1944 was nearly 32,000,000 tons of copper.

Foreign copper has entered foreign markets formerly supplied by the United States, and in addition has even threatened competition in the domestic market. A 4-cent excise tax imposed in 1932 prevented much foreign copper from entering the country except for treatment under bond. During the war just ended the United States Government purchased large quantities of foreign copper for munitions. Although these purchases have exaggerated the degree to which the United States has become an importing nation, the decline in the competitive position of United States producers is evident.

Reserves

The availability of reserves under the economic and technologic conditions prevailing in January 1944 was considered as best established through actual extraction of ore during 1942 and 1943. Reserves in mines that were not operating during that period are included in the estimate if they are comparable to deposits being exploited profitably at that time under the quota-premium plan, the price of copper ranging from 12 to 27 cents. Appropriate credits for byproducts of precious and base metals have been taken into account.

As of January 1, 1944, available reserves of copper ore in the United States were estimated to contain about 20,000,000 tons of copper recoverable under conditions at that time. (See table 16.) This metal was contained in approximately 2,090,000,000 tons of ore with an average copper content of about 1.1 percent. Approximately one-half of this metal, or 10,000,000 tons, was contained in reserves that had been reported in statements published by operators. An additional 5,000,000 tons of copper was estimated to be recoverable from reserves that had been developed or indicated later by the operators. These two categories together comprised approximately 15,000,000 tons of recoverable copper, the availability of which was reasonably assured. Approximately 70 percent of this reserve was in porphyry-copper ore that had been measured or indicated by drilling, and the remainder consisted of ore reserves of comparable assurance in vein and other types of deposits. Data were not available to permit the specific allocation of measured and indicated ore, hence the two categories were reported together. Normal development and mining of the measured and indicated reserves should lead to the discovery of additional ore containing approximately the 5,000,000 tons of inferred copper reported in the table. Most of these reserves have been inferred in vein and other deposits that, unlike the porphyry-copper deposits, cannot be estimated accurately in advance of mining. The inferred reserves comprise only prospective extensions of known ore bodies or mineralized areas of proved value and include no allowance for new discoveries of ore that may be made in future in other areas.

TABLE 16.—*Estimated available copper resources of the United States as of January 1944*

[In short tons]

MEASURED AND INDICATED RESERVES

	Ore	Copper content (percent)	Recoverable copper
A. DISTRIBUTION BY REGIONS			
Eastern and Central States	160,000,000	0.6	840,000
Western States and Alaska	1,490,000,000	1.1	14,160,000
Total	1,650,000,000	1.1	15,000,000
B. AVAILABILITY BY MINING METHODS			
Surface methods	1,260,000,000	1.0	10,520,000
Underground methods	390,000,000	1.3	4,480,000
Total	1,650,000,000	1.1	15,000,000

RECENT PRODUCTION BY DISTRICTS
(in short tons of copper)

Production in 1943, or estimated production capacity in 1944

More than 75,000 tons
1. Bingham, Utah
2. Butte, Montana
3. Globe-Miami, Arizona
4. Morenci, Arizona

10,000 to 75,000 tons
5. Ajo, Arizona
6. Bisbee, Arizona
7. Central, New Mexico
8. Ely, Nevada
9. Jerome, Arizona
10. Lake Superior, Michigan
11. Ray, Arizona
12. Superior, Arizona

5,000 to 10,000 tons
13. Eureka (Bagdad), Arizona
14. Chelan, Washington
15. Cope, Nevada
16. Cornwall, Pennsylvania
17. Ducktown, Tennessee
18. Siskiyou County, California

1,000 to 5,000 tons
19. La Sal (Big Indian), Utah
20. Calaveras County, California
21. Coeur d'Alene, Idaho
22. Lordsburg, New Mexico
23. Orange County, Vermont
24. Shasta County, California
25. Southeastern Missouri
26. Tyrone, New Mexico

Production from other districts during the period 1938 - 1943:

More than 1,000 tons in any year
27. Bunker Hill, Arizona
28. Copper River, Alaska
29. Ophir, Utah
30. Plumas County, California
31. Red Cliff, Colorado
32. San Juan Mountains, Colorado
33. San Pedro, New Mexico
34. Swain County, North Carolina
35. Tintic, Utah

Less than 1,000 tons in any year
36. Banner, Arizona
37. Battle Mountain, Nevada
38. Bishop Creek, California
39. Jack Rabbit, Nevada
40. Old Hat, Arizona
41. Park City, Utah
42. Patagonia, Arizona

Less than 1,000 tons during the period
43. Gossan Lead, Virginia
44. Orange Hill, Alaska
45. Silver Bell, Arizona
46. Snohomish County, Washington
47. Yerington, Nevada

CHART VIII.—Distribution of recent copper production and major copper reserves of the United States and Alaska as of January 1944, by districts.

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TABLE 16.—*Estimated available copper resources of the United States as of January 1944*—Continued

INFERRED RESERVES

A. DISTRIBUTION BY REGIONS			
Eastern and Central States	180, 000, 000	0. 7	1, 160, 000
Western States and Alaska	260, 000, 000	1. 6	3, 840, 000
Total	440, 000, 000	1. 25	5, 000, 000
B. AVAILABILITY BY MINING METHODS			
Surface methods	25, 000, 000	1. 0	220, 000
Underground methods	415, 000, 000	1. 3	4, 780, 000
Total	4[illegible]0, 000, 000	1. 25	5, 000, 000

TOTAL RESERVES

A. DISTRIBUTION BY REGIONS			
Eastern and Central States	340, 000, 000	0. 7	2, 000, 000
Western States and Alaska	1, 750, 000, 000	1. 2	18, 000, 000
Total	2, 090, 000, 000	1. 1	20 000, 000
B. AVAILABILITY BY MINING METHODS			
Surface methods	1, 285, 000, 000	1. 0	10, 740, 000
Underground methods	805, 000, 000	1. 3	9, 260, 000
Total	2, 090, 000, 000	1. 1	20, 000, 000

The lowest grades of ore included in the estimates vary widely with local conditions, ranging from about 0.8 percent for certain vein deposits and about 0.4 percent for some of the porphyry coppers to less than 0.2 percent in reserves from which copper is recovered only as an important byproduct.

Marginal resources in the United States were estimated to include 10 million tons of copper contained in 1.25 billion tons of material in mine dumps and tailings, as well as in rock in place. This conservative estimate of marginal copper includes only the resources for which available data were sufficient to permit appraisal. The tailings of the porphyry-copper operations, for example, have not been included. Low-grade copper deposits at shallow depths were included if the grade of rock in place averaged at least 0.4 percent of copper, and higher averages were used for less accessible ore left in large pillars or at depth in former mining operations. Correspondingly lower averages were used for dumps and tailings and for material from which copper might be recovered as a byproduct in connection with the extraction of other metals or minerals. Although these resources are not believed to be commercially available under present conditions, some portion of this copper may be recoverable at some future time.

Possible trends in the future depletion of the resources here estimated can be visualized in general terms, in relation to possible future economic trends. If the conditions that prevailed in January 1944 continued indefinitely, the estimated available reserve could probably support production at an annual rate that might average about 1,000,000 tons for nearly 10 years, declining thereafter until virtual exhaustion of the estimated reserve after about 30 years. In January 1944 the price of copper was quited at 12 cents per pound for electrolytic grade delivered, Connecticut Valley. Actually, the price to the miner ranged from 12 to 27 cents as a result of Government premiums in the form of subsidies to mines producing in excess of certain previous rates. Or, if conditions are soon established comparable to those that prevailed during the period 1923–28, when copper averaged about 14 cents a pound, most of the same reserve could be considered available to support production at a lower initial rate, declining more gradually over a longer period of years. The average annual production of copper for 1923–28 was about 800,000 tons. The increased production during the recent war as compared with 1923–28 arose principally from important increments in output at a few of the larger mines, stimulated by the premiums and other less tangible incentives.

More extreme economic conditions than those visualized above can obtain, and their possible effects on future depletion can be briefly contrasted. Condi-

tions more favorable to the copper industry than those of 1944 would have the effect of making available those resources that are now classed as marginal, so that production on the order of 1,000,000 tons a year could be sustained over a correspondingly longer period. Conversely, an unduly weak market for domestic copper over a prolonged period might result in closing all but a few of the lowest-cost mines in the United States, but even under adverse circumstances these mines should be able to produce at a moderate rate of possibly several hundred thousand tons for many years.

The position of copper resources of the United States in the years ahead will be determined, however, by the interplay of many factors. Today's reserve are being depleted, but new discoveries of deposits and new developments in technology will provide additional reserves. This process of replenishment will respond to the strength of future demand for copper as surely as will the rate of production, but the net effect of these complex factors over a period of years cannot be foreseen at present.

Industrial Diamonds

By Oliver Bowles[48] and C. S. Ross[49]

Diamonds for cutting tools of various kinds attained remarkable importance during World War II. Before the war the United States consumed about 1.25 million carats of industrial diamonds a year, but consumption increased to at least 10 million carats in 1943. Although this phenomenal increase was due in large part to the heavy demands for precision machine-tool work on war equipment, much of the gain probably will be retained in postwar times. Thus continuing heavy demand, possibly twice as great as in prewar years, is to be anticipated.

At least 90 percent of the world's supplies are obtained in Africa and 10 percent or less in Brazil. Other sources are of small importance.

Except for occasional diamonds found in glacial drift, the only natural source of supply in the United States is deposits near Murfreesboro, Ark. Up to 1925 the output amounted to at least 10,000 stones of various sizes. The only recent year for which commercial production has been reported is 1932, when the output was said to have been 593 diamonds having a total weight of 308 carats. Of this quantity, 422 diamonds weighing 189 carats were classed as industrial.

The history of past production and reports on the deposits by geologists indicate that domestic reserves are inadequate to supply more than a minute fraction of domestic requirements. Consequently, the United States must depend upon foreign supplies for virtually 100 percent of its needs.

Fluorspar

By H. W. Davis,[50] Albin C. Johnson,[50] and James Steele Williams[51]

Fluorspar is a mineral aggregate or mass composed of sufficient quantities of the mineral fluorite, calcium fluoride (CaF_2), to have commercial interest. It is used as a flux in the steel industry; in the manufacture of hydrofluoric acid, which in turn is used principally in making aluminum, high-octane gasoline, refrigerants, and insecticides; in the manufacture of glass and enamel; and in numerous miscellaneous operations. In normal times, for use in the steel industry the material should contain 85 percent of CaF_2 and not more than 5 percent of SiO_2 (silica) and 0.3 percent of S (sulfur); such material is called "metallurgical-grade fluorspar." Under war conditions fluorspar of much lower grade was accepted by many steel manufacturers. Lead and zinc are undesirable impurities in metallurgical-grade fluorspar. In the manufacture of hydrofluoric acid, the material should contain at least 98 percent of CaF_2 and not more than 1 percent each of SiO_2 and $CaCO_3$; such material is called "acid-grade fluorspar." Over 0.02 percent of sulfur is considered undesirable in fluorspar of this grade, and the moisture content should be less than 1 percent.

In 1944 the steel industry used 56 percent and the hydrofluoric acid industry 32 percent of the total fluorspar consumed in the United States. At present there is no substitute, either in quantity or quality, for fluorspar in the manufacture of

[48] Bureau of Mines.
[49] Geological Survey.
[50] Bureau of Mines.
[51] Geological Survey.

hydrofluoric acid, and no other substance appears to be as satisfactory as a flux in the steel industry. Calcium chloride is a substitute for metallurgical-grade fluorspar, but several times more of it are required. Limestone, various compounds of sodium and potassium, bauxite, and ilmenite also have been used experimentally and to a small extent. Mixing of fluorspar with roll scale decreases the amount of fluorspar necessary.

Through 1944, Illinois had contributed 54 percent and Kentucky 35 percent of domestic fluorspar output; most of the remaining 11 percent has come from Colorado and New Mexico. In 1944 alone, however, these two Western States produced 30 percent of the total.

Figure 15 shows production, imports, and consumption from 1910 to 1944 and the range in price for that period. The graph indicates that production responds

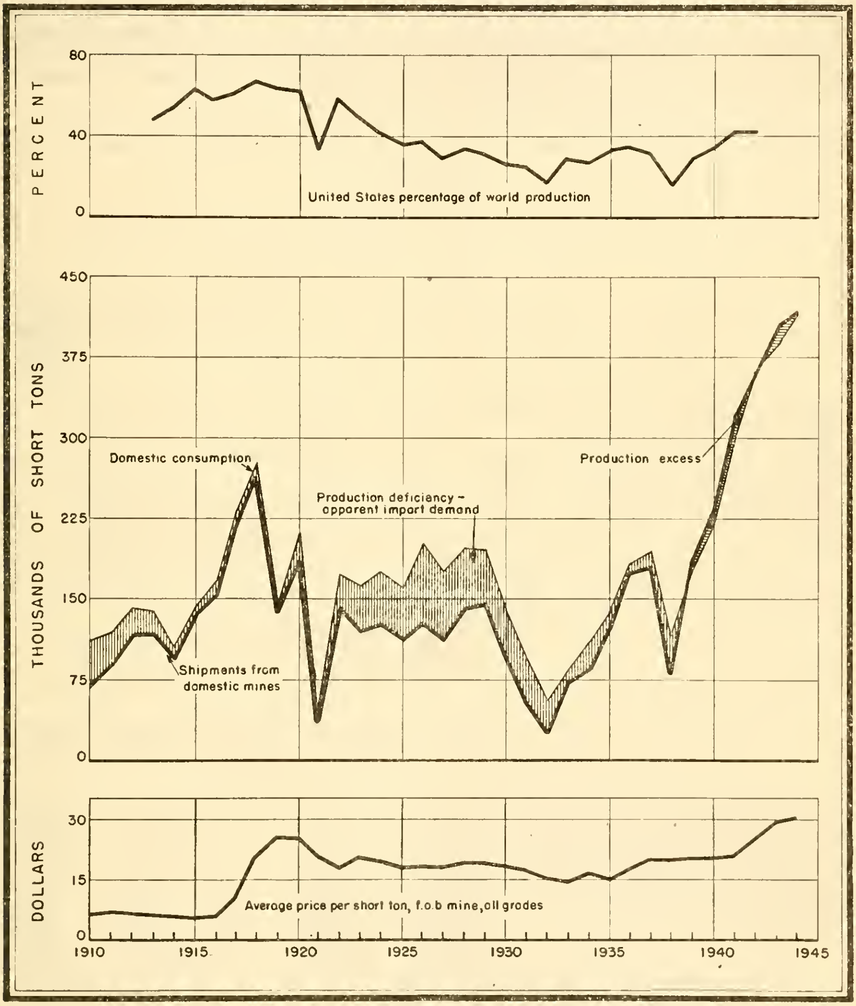

FIGURE 15.—Trends in production, consumption, and price of fluorspar in the United States, 1910–44.

to price and that when the price was high enough the United States could produce for a few years enough fluorspar to meet its requirements. However, under normal conditions considerable fluorspar is imported.

Several low-grade deposits of fluorspar that contain large amounts of undesirable minerals finely intermixed with the fluorite can be exploited for metallurgical-grade uses when economic conditions permit milling of the material by flotation and agglomerating of the concentrates for use in the manufacture of steel. Improved methods of agglomerating, one of which has been developed by the Bureau of Mines, will aid this type of use. Other low-grade deposits that contain large amounts of barite can be used when methods of separating fluorspar from barite are proved commercially feasible.

Reserves.—The largest fluorspar deposits in the United States are in the districts and States that are now producing the largest amounts of fluorspar; accordingly, by far the largest reserves of fluorspar are in the Kentucky-Illinois field and the next largest in Colorado and in New Mexico. (See chart IX.) Other States having important but less-developed fluorspar resources are Nevada, Texas, Utah, Idaho, Montana, Arizona, California, and Wyoming. In Alaska, fluorspar deposits are known at the Lost River tin mine on Seward Peninsula, and fluorite has been reported from Zarembo Island and from a locality near Wrangell in southeastern Alaska, but no fluorspar has been mined.

TABLE 17.—*Estimated fluorspar reserves of the United States as of January 1944, by regions*

[In short tons]

Region	Material (ore) containing 35 percent or more of CaF_2					
	Measured	Indicated	Inferred	Total crude material	CaF_2 content	Average grade (estimated percent CaF_2)
Kentucky and Illinois	1,722,000	2,328,000	7,000,000	11,050,000	5,525,000	50
Rocky Mountain States (Colorado, Utah, Idaho, Wyoming, Montana)	104,000	782,000	1,250,000	2,136,000	961,200	45
Southwestern States (Arizona, New Mexico, Texas)	102,000	209,000	800,000	1,111,000	610,500	55
Pacific Coast States and Nevada	7,000	30,000	80,000	117,000	81,900	70
All other States			4,000	4,000	2,000	50
Alaska		56,000	250,000	306,000	128,500	42
Total	1,935,000	3,405,000	9,384,000	14,724,000	7,309,100	49

Region	Material containing 15 to 34 percent of CaF_2 [1] (measured, indicated, and inferred)			Total	
	Crude material	CaF_2 content (estimated)	Average grade (estimated percent CaF_2)	Crude material	CaF_2 content
Kentucky and Illinois	4,500,000	675,000	15	15,550,000	6,200,000
Rocky Mountain States (Colorado, Utah, Idaho, Wyoming, Montana)	3,500,000	700,000	20	5,636,000	1,661,200
Southwestern States (Arizona, New Mexico, Texas)	1,000,000	200,000	20	2,111,000	810,500
Pacific Coast States and Nevada	450,000	90,000	20	567,000	171,900
All other States	140,000	28,000	20	144,000	30,000
Alaska	2,000	400	20	308,000	128,900
Total	9,592,000	1,693,400	18	24,316,000	9,002,500

[1] Based on incomplete data and believed to be conservative.

Table 17 shows the available fluorspar reserves of the United States as of January 1944. The group containing 35 percent or more of CaF_2 includes nearly all the known deposits that are workable under economic and technologic conditions similar to those in 1944, as well as some deposits that cannot now be mined economically because they are remote from markets, are subject to unusually

FLUORSPAR

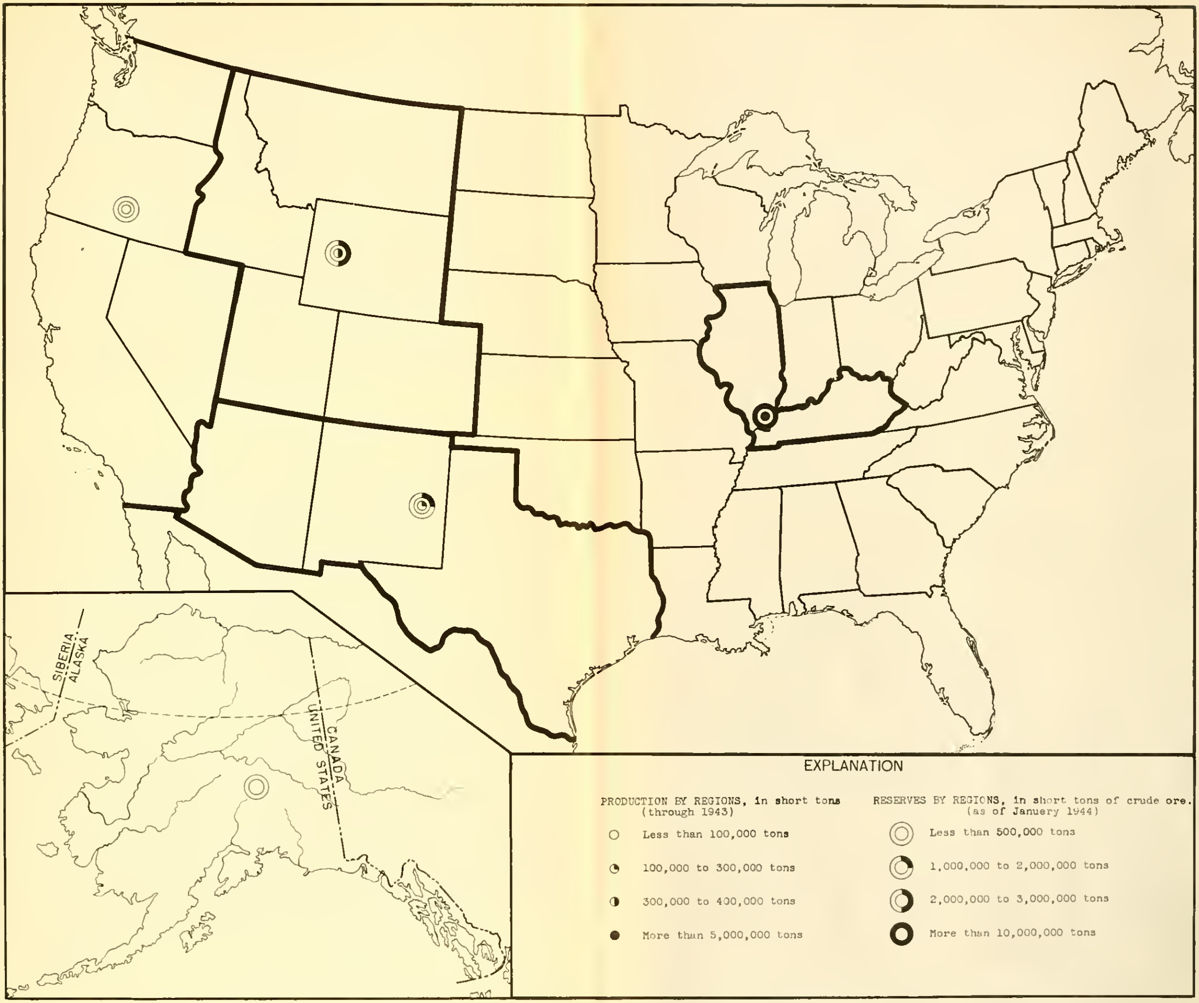

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CHART IX.—Distribution of total production of fluorspar in the United States through 1943 and available reserves of crude ore containing 35 percent or more of CaF_2 as of January 1944, by regions.

high mining or milling costs, or contain excessive amounts of undesirable impurities. In some areas it is not profitable to mine fluorspar containing less than 50 percent of CaF_2. A very few deposits, omitted from this group because they contain less than 35 percent of CaF_2, may be minable even though they contain as little as 30 percent of CaF_2, because they are near markets and are of such type that they can be easily mined and processed. Deposits containing less than 1,000 tons have been excluded from the summary.

The estimates of material containing 15 to 34 percent of CaF_2 are based on incomplete data and are believed to be conservative. Relatively few deposits of this grade have been investigated. Material containing less than 15 percent of CaF_2 has not been included in the estimate because there seems little likelihood that it will be utilized until so far into the future as to have little significance at present.

Chart IX shows the distribution of past production and estimated reserves of fluorspar in the United States.

The estimated reserves of fluorspar in ore containing 35 percent or more of CaF_2 are equivalent to roughly 20 years' supply at the wartime rate of use and about 40 years' supply at the average rate from 1935 to 1939. However, known resources of fluorspar ore could not support production sufficient to take care of full domestic needs for the 20 to 40 years mentioned because of the declining rate of production that accompanies depletion. Insufficient data are available to estimate productivity of deposits that are not minable under economic and technologic conditions existing in 1944. A rough estimate of 10 to 25 years of normal prewar supply in material containing from 15 to 34 percent of CaF_2 is probably conservative.

Gold

By F. M. Chace,[52] McHenry Mosier,[53] and C. E. Needham[53]

Gold is used chiefly as a base for the monetary systems of the world and in the settlement of international trade balances. The amount now used for coinage, however, is relatively small, and most of the gold produced is kept by governments and central banks in reserve for the issuance of notes. Considerable gold is used for ornamentation, principally jewelry, gold plating, gold braid, glass and china inlays, gilding, bookbinding, lettering, and interior decorations. In the arts and sciences gold is used in dentistry, chemical plant and laboratory ware, thermocouples, cases and parts for chronometers and watches, galvanometers, radio conductors, water-meter recorders, motor-generator brushes, X-ray equipment, radium therapy, special high-temperature lead fuses, electrical contacts, sound-transmitting apparatus, and photography.

Substitutes for gold are platinum-group metals in jewelry; enamels, plastics, mercury, and palladium alloys in dentistry; stainless steel, chromium, and nickel alloys in corrosion-resistant equipment; and tantalum and platinum in laboratory apparatus. These substitutes are satisfactory and adequate in specific fields. However, no completely satisfactory substitute for gold has been found in the world monetary systems.

Gold is obtained from several types of ore deposits, including placers, gold-quartz veins, and replacement bodies in metamorphic and other rocks; and as a byproduct of the mining of base metals, principally copper, lead, and zinc. During the early days of the United States and following the gold discoveries in California during 1848 and 1849, gold was produced from placers. As most of the richer deposits of this type became exhausted, an increasing proportion of the production was derived from lodes. Placer mining is now carried on extensively in certain areas with large bucket-line and other types of dredges, but the greater part of the output is derived from lode deposits and as a byproduct of base-metal mining. Besides gold-bearing base-metal ores, gold ores are commonly classified as dry ores or as siliceous ores. A dry ore is one containing lead, zinc, or copper—but not in sufficient amount to pay the treatment charges before crediting the gold. A siliceous gold ore contains silica in excess of iron, and virtually all of its value is derived from gold.

[52] Geological Survey.
[53] Bureau of Mines.

The annual domestic gold production from 1910 to 1944 is shown graphically in figure 16. An additional curve in figure 16 shows the relationship between the purchasing power of the dollar and the production of gold. The United States percentage of the total world gold production is given in a third curve. The distribution of gold production, by States, is shown on chart X.

FIGURE 16.—Trends in production and purchasing power of gold in the United States, 1910–44.

Reserves

The estimated gold reserves of the United States, including Alaska, as shown in table 18, are approximately 69,000,000 troy ounces of recoverable gold, which, at $35 an ounce, have a total value of nearly $2,500,000,000, equivalent to about 11 percent of the present monetary stock of gold of the United States Government.

Of this reserve, approximately 21,000,000 ounces is in placers, 37,000,000 ounces in dry and siliceous ores, and 11,000,000 ounces in base-metal ores, chiefly the disseminated-copper deposits. Data are not available in sufficient detail to permit showing measured and indicated reserves separately.

These estimates are based on economic conditions as they were in 1940 before disruption by war and on current technologic knowledge.

At the 1910 rate of production (4,900,000 ounces), these reserves would have a life of 14 years. However, all the deposits will not be exhausted at the same time, and new ore deposits may be found. Consequently production will continue beyond the 14 years indicated above. The future output of gold is closely related to economics. Variations in base-metal prices, the cost of labor and supplies, and changes in the purchasing power of the dollar will be reflected in the production of gold. Improved technology, a decrease in over-all operating costs, or an

GOLD

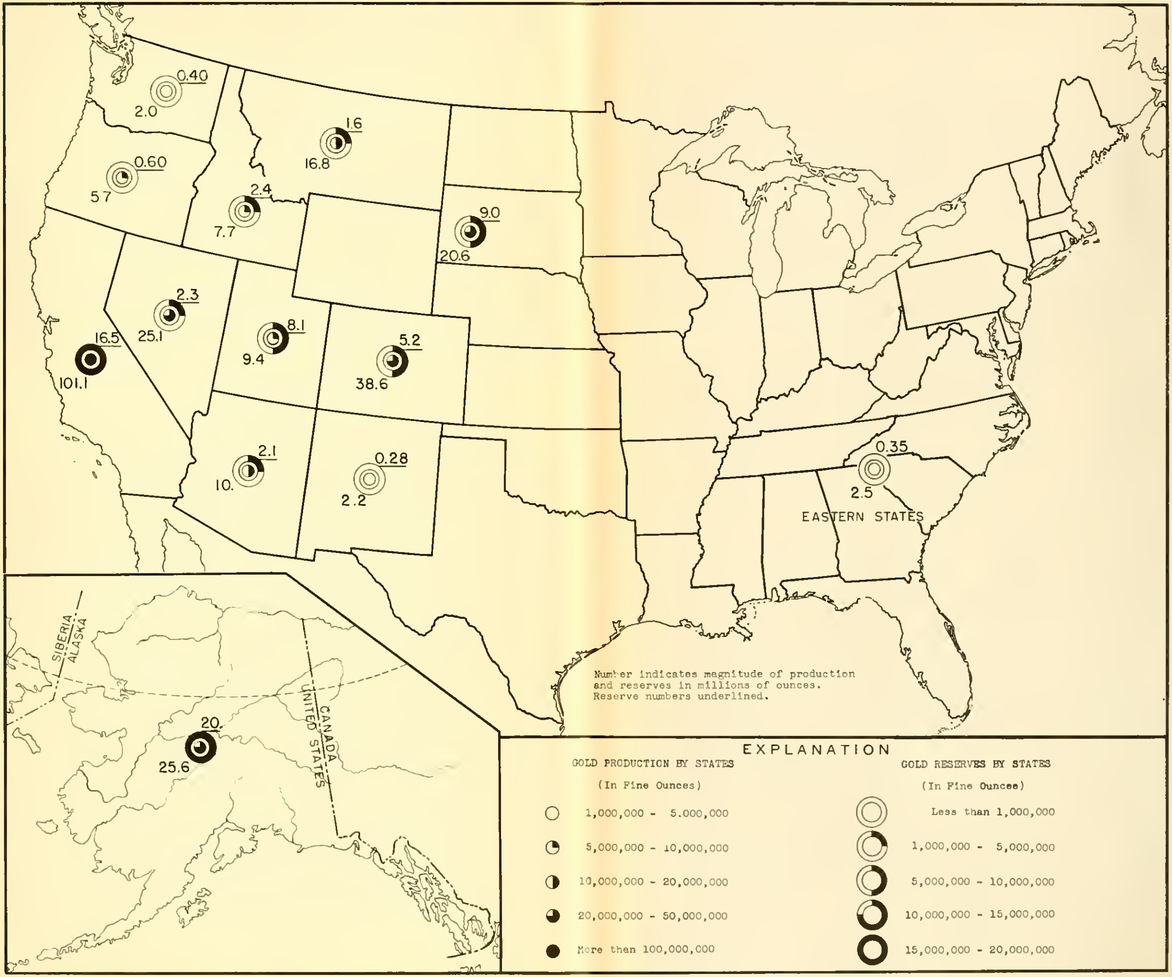

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CHART X.—Total production of gold through 1943 and estimated reserves as of January 1944, by States.

increase in the price of gold would increase gold reserves and might make production possible from certain high-level gravels in California, some old mines in Oregon, certain placers in Idaho and Washington, and submarginal ore bodies in gold-producing areas. This would add a few million ounces to the reserves.

TABLE 18.—*Estimated recoverable gold reserves in the United States as of January 1944*

[In troy ounces]

Location	Measured and indicated	Inferred	Total
Alaska	7,000,000	13,000,000	20,000,000
Arizona	1,800,000	300,000	2,100,000
California	7,325,000	9,200,000	16,525,000
Colorado	2,000,000	3,200,000	5,200,000
Idaho	750,000	1,720,000	2,470,000
Montana	1,000,000	600,000	1,600,000
Nevada	1,550,000	800,000	2,350,000
New Mexico	180,000	100,000	280,000
Oregon	250,000	350,000	600,000
South Dakota	6,000,000	3,000,000	9,000,000
Utah	7,000,000	1,150,000	8,150,000
Washington	175,000	225,000	400,000
Eastern States	100,000	250,000	350,000
Total	35,130,000	33,895,000	69,025,000

GRAPHITE

By L. W. Currier,[54] G. R. Gwinn,[55] and W. H. Waggaman[55]

Graphite is a soft, crystalline form of carbon. Natural graphite occurs and is used in a variety of types, which are broadly classified as "crystalline" and "amorphous," the essential difference being in the size of the particles. Graphite has an unctuous quality that makes it valuable as a lubricant. It withstands high temperatures, is a good conductor of heat and electricity, and is inert to many reagents. Because of these properties, graphite is used in a wide range of products. Only the coarser crystalline varieties—lump, chip, and flake graphite—are suitable for certain strategic uses. They are employed chiefly in the manufacture of crucibles and other metallurgical equipment, dry batteries, lubricants, and packings; under normal conditions, the United States produces very little graphite of the type (chiefly flake) desired for these purposes. Madagascar supplies most of the flake graphite for metallurgical purposes, largely because of the high quality of graphite there and its relatively low production cost. Domestic flake is acceptable for use in foundry facings, lubricants, dry batteries, and some minor purposes. Natural "amorphous" graphite is used extensively in carbon brushes, foundry facings, car washes, pencils and crayons, lubricants, paints, dry batteries, shoe and stove polishes, and many other commodities.

Artificial "amorphous" graphite is manufactured on a large scale in the United States. It is used chiefly in electrodes for electric furnaces and also in many cases in place of the natural product.

Clay and ceramic materials also can be substituted for graphite to some extent. Changes in metallurgical practices since World War I have considerably reduced the use of graphite crucibles. With advances in technology, the cost of producing domestic flake graphite may be reduced, but the current outlook is for a continued high-cost product. Substitution of domestic for imported flake graphite in crucible manufacture at present would increase costs and reduce the quality of the crucible. Scrap recovery of graphite is negligible.

Data on domestic production of natural graphite for the decade before World War II are not available, but it was intermittent and relatively small compared with national requirements. In 1939, approximately 21,500 short tons of natural graphite was imported, of which 2,800 tons was classified as flake, chip, or lump,

[54] Geological Survey.
[55] Bureau of Mines.

and 18,700 tons as "amorphous." Mexico and Ceylon were the principal sources of "amorphous" graphite, and Madagascar and Ceylon contributed most of the crystalline. In 1943 domestic production, all grades, totaled 9,939 tons and imports 28,713 tons; of the latter, 6,323 tons was crystalline and 22,390 "amorphous" graphite.

The productive domestic deposits are in east-central Alabama, eastern New York, southeastern Pennsylvania, and Burnet County, Tex. Small deposits at Dillon, Mont., have been worked intermittently, but without notable success; the graphite from this locality more closely resembles Ceylon graphite than does any other known domestic graphite. At Sturbridge, Mass., a single graphite vein has been worked for several short periods, and lump graphite of high quality was obtained in small amounts. Deposits of unknown extent and quality have been reported to occur in Alaska, California, New Jersey, North Carolina, Virginia, and Wyoming.

Reserves

Table 19 lists the resources of graphite in the United States, as estimated in 1944. Although there are wide variations in the nature of domestic ores and the quality of the graphite derived from them, an attempt at appraising reserves according to grade has been made. It is estimated that less than a fifth of the total shown can be classed as flake graphite. Data at hand do not permit an estimate of the reserves available under normal commercial conditions, but they are believed to be relatively small.

Were they of suitable quality, the reserves of flake graphite as estimated—150,000 to 215,000 short tons—would be equivalent to 60 to 85 years supply at the prewar rate of use and 35 to 50 years' life at the wartime rate. In addition, geologic data indicate that potential but unestimated resources are probably very large, and that, under conditions of necessity, exploration, and development of known graphite districts, particularly in New York and Alabama, would yield considerable flake graphite. However, as stated previously, the domestic product is not a fully satisfactory substitute for the high-grade imported flake preferred by industry.

TABLE 19.—*Graphite reserves of the United States as estimated in 1944, by States*

[In short tons]

State	Graphite content of crude ore (percent)	Estimated reserves of graphite							
		Measured		Indicated		Inferred		Total	
		Flake	Fine	Flake	Fine	Flake	Fine	Flake	Fine
Alabama	2 to 4	40,000–50,000	125,000–150,000	None	None	None	None	40,000–50,000	125,000–150,000
New York	4 to 6	None	None	(1)	(1)	100,000–150,000	500,000	100,000–150,000	500,000
Pennsylvania	4.5 to 5	10,000–15,000	25,000–40,000	(2)	(2)	None	None	10,000–15,000	25,000–40,000
Texas	5	(3)	None	(3)	150,000	(3)	None		150,000
Total								150,000–215,000	800,000–840,000

[1] Estimate included in tonnage shown under inferred reserves.
[2] Estimate included in tonnage shown under measured reserves.
[3] Data insufficient to permit separate estimates for measured, indicated, and inferred.

Helium

By N. W. Bass,[56] H. S. Kennedy,[57] and K. H. Johnston[57]

Helium is a noninflammable gas present, with other gases, in some natural-gas fields. Today millions of cubic feet of helium are used by the Army and Navy for inflating lighter-than-air ships and barrage balloons, for deep-sea diving and caisson work, and for several secret defense uses. Large quantities lift meteorological balloons as a part of the weather-forecasting activities of the Weather Bureau and the Armed Forces. Smaller volumes are being used in a new industrial process—the heliarc welding method for magnesium—and by the medical profession for the treatment of asthma and other respiratory diseases. In the operating room, helium is mixed with anesthetics to prevent or minimize the danger of fires and explosions.

Helium is present in important amounts in many gas fields in Texas, Kansas, New Mexico, Utah, Colorado, Oklahoma, Wyoming, Michigan, and Ohio. The deposits in Wyoming, Michigan, and Ohio are of doubtful present value, however, because the helium content is less than in the gas pools of the other States listed. Chart XI shows the geographic distribution of the major helium-bearing gas fields. The absence of significant quantities of helium in gas from large fields of California and the Gulf coast and from most parts of the Appalachian region is noteworthy.

Except for the Model Dome gas field in Colorado, helium deposits of commercial value are associated with hydrocarbon gases. The helium content of the gas in most of the important helium-bearing gas fields ranges from 0.9 to 2 percent; the Rattlesnake gas field of New Mexico, however, yields gas of approximately 7½ percent helium content.

Helium-rich gas has been found at depths ranging from about 300 feet at Dexter, Kans., to 7,000 feet in the Rattlesnake field, at Shiprock, N. Mex. The helium-bearing gas is found commonly in several zones and therefore at several depths in the same field. Rocks containing helium apparently include all those that commonly form reservoirs for oil or ordinary gas.

Since 1938 helium has been produced in the United States solely by the Federal Government, through the Bureau of Mines. In 1944, five plants were in operation. One at Amarillo, Tex., having a rated capacity of 36 million cubic feet of helium a year; one at Exell, Tex., having a rated capacity of 60 million cubic feet; and one each at Otis, Kans., Cunningham, Kans., and Shiprock, N. Mex., each having a rated capacity of 48 million cubic feet a year. Other supplies of helium are known, but they are inferior to that from the fields that have been selected to supply the existing helium plants, and their use would increase the production cost materially.

When these plants were placed in operation, it was found that they could produce approximately 30 percent more than their rated capacities, owing to improvements in the design of the extraction equipment. They were able to meet all war requirements.

Figure 17 shows helium production, by fiscal years, from Government-owned plants. The total yield to January 1, 1944, was 327 million cubic feet.

The price at which helium can be sold is influenced by the volume of production and improvements in the process. Over a period of years, the price of helium has shown a marked decrease. For example, the price to large-scale Government users, exclusive of service charges, declined from $11.16 per thousand cubic feet in 1938 to $6.29 in 1944.

Reserves

The estimated reserves available to the five helium plants are approximately 8 billion cubic feet of helium. The volume of helium to be obtained from the fields furnishing the Exell, Tex., and the Otis and Cunningham, Kans., plants depends upon the productive and operating capacities of the plants, because the Government does not control the gas withdrawal from those fields. If the plants are operated below capacity, which probably will be the case, part of the gas produced from the fields will not be processed, and the helium content will be lost. At Exell it is feasible to process all gas produced and to store the helium undergrounds in the Cliffside gas field, which is nearby and is owned by the Government.

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[56] Geological Survey.
[57] Bureau of Mines.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY AND BUREAU OF MINES

HELIUM

MINERAL RESOURCES OF THE UNITED STATES

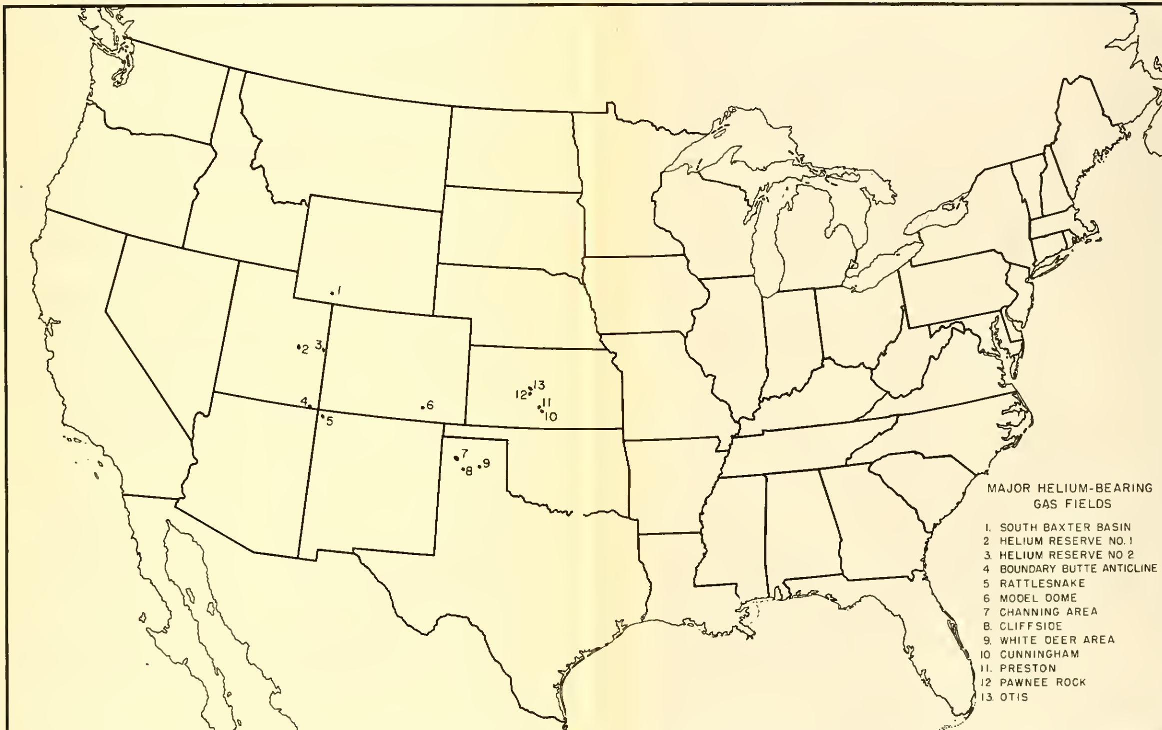

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CHART XI.—Distribution of the major helium-bearing gas fields in the United States.

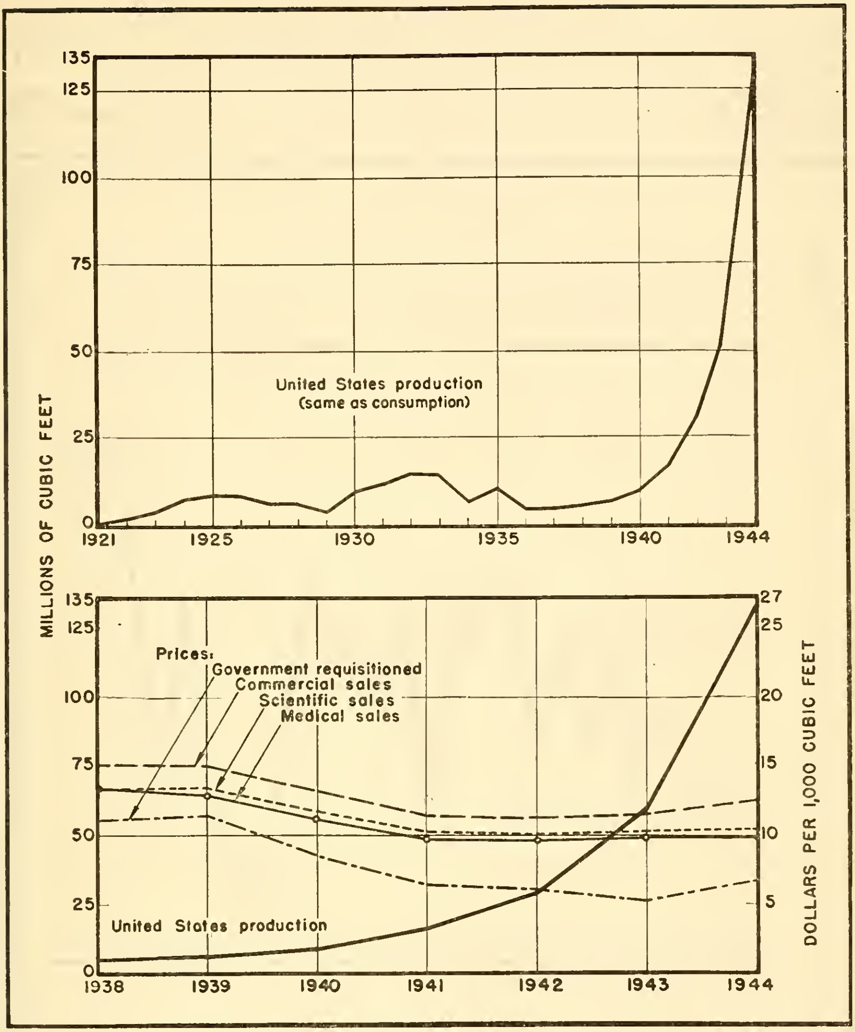


FIGURE 17.—Production of helium in the United States, fiscal years ended June 30, 1921–44, and price trends, fiscal years 1938–44.

The most practicable guide in a search for new helium deposits is the distribution of the known helium-bearing gas pools. Additional discoveries are to be expected within the regions containing proved deposits.

IRON ORE

By Ernest F. Burchard,[58] Albin C. Johnson,[59] and Norwood B. Melcher [59]

Next to aluminum, iron is the most abundant metal in nature. Most rocks contain it, at least in small quantities, but few are rich enough or of such physical and chemical nature as to constitute iron ore. The four principal kinds of iron ore are: (1) Hematite or red iron ore; (2) magnetite or magnetic ore; (3) the so-called "limonite" or brown ore, and (4) siderite or carbonate ore. Hematite is by far the most abundant and constitutes about 90 percent

[58] Geological Survey.
[59] Bureau of Mines.

of the total mined. Magnetite and brown ore rank next. A small quantity—592,908 tons—of cinder and sinter from the roasting of pyrite (iron sulfide) in the manufacture of sulfuric acid were shipped as iron ore to steel and blast furnaces during 1944.

Although there is some export and import trade, the United States is virtually self-sufficient in iron ore. Figure 18 shows the relation between domestic and world production.

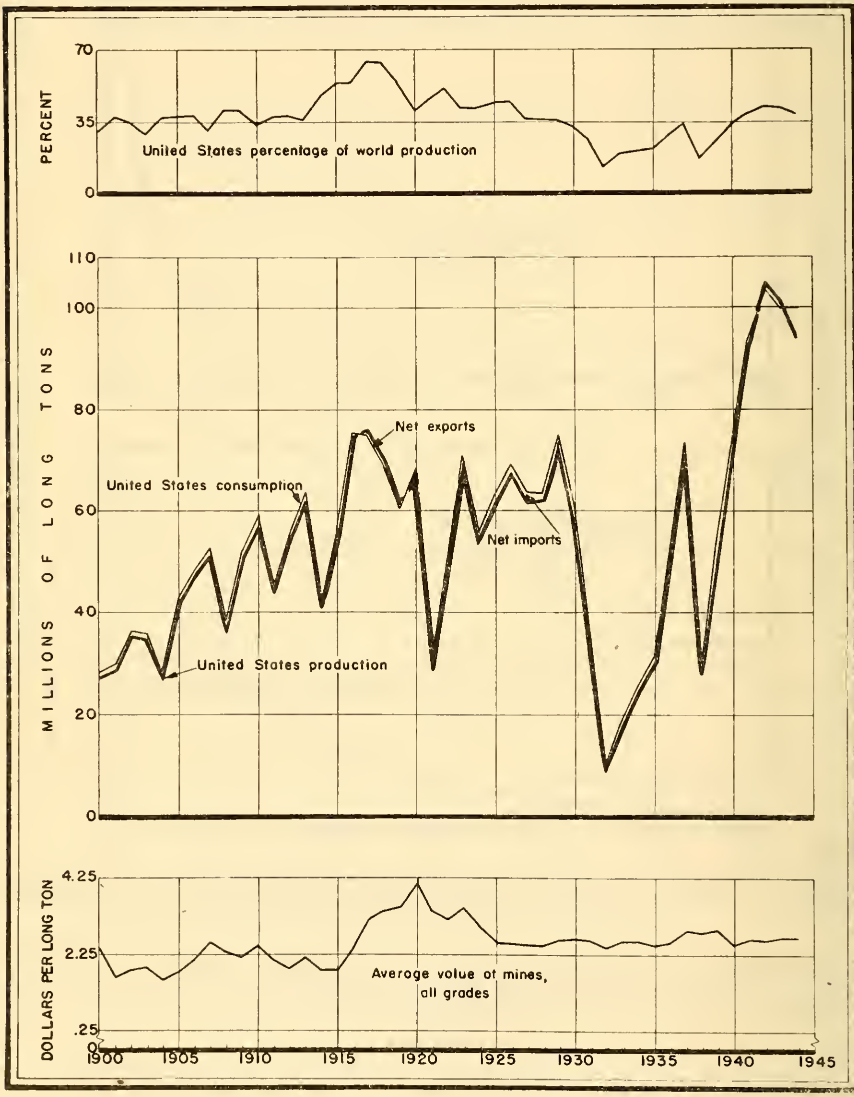


FIGURE 18.—Trends in production, consumption, and price of iron ore in the United States, 1900–44.

Iron-ore production, which closely follows the demand for steel, is one of the first industries to respond to changes in industrial activity. As most ore is mined from open-cuts or shallow workings, it is relatively easy to adjust operations to economic demands. Price has little immediate effect upon iron-ore output, except that periods of high industrial activity are usually accompanied by higher prices. The heavy demand for steel during major wars elevates the production of iron ore to record levels.

IRON ORE

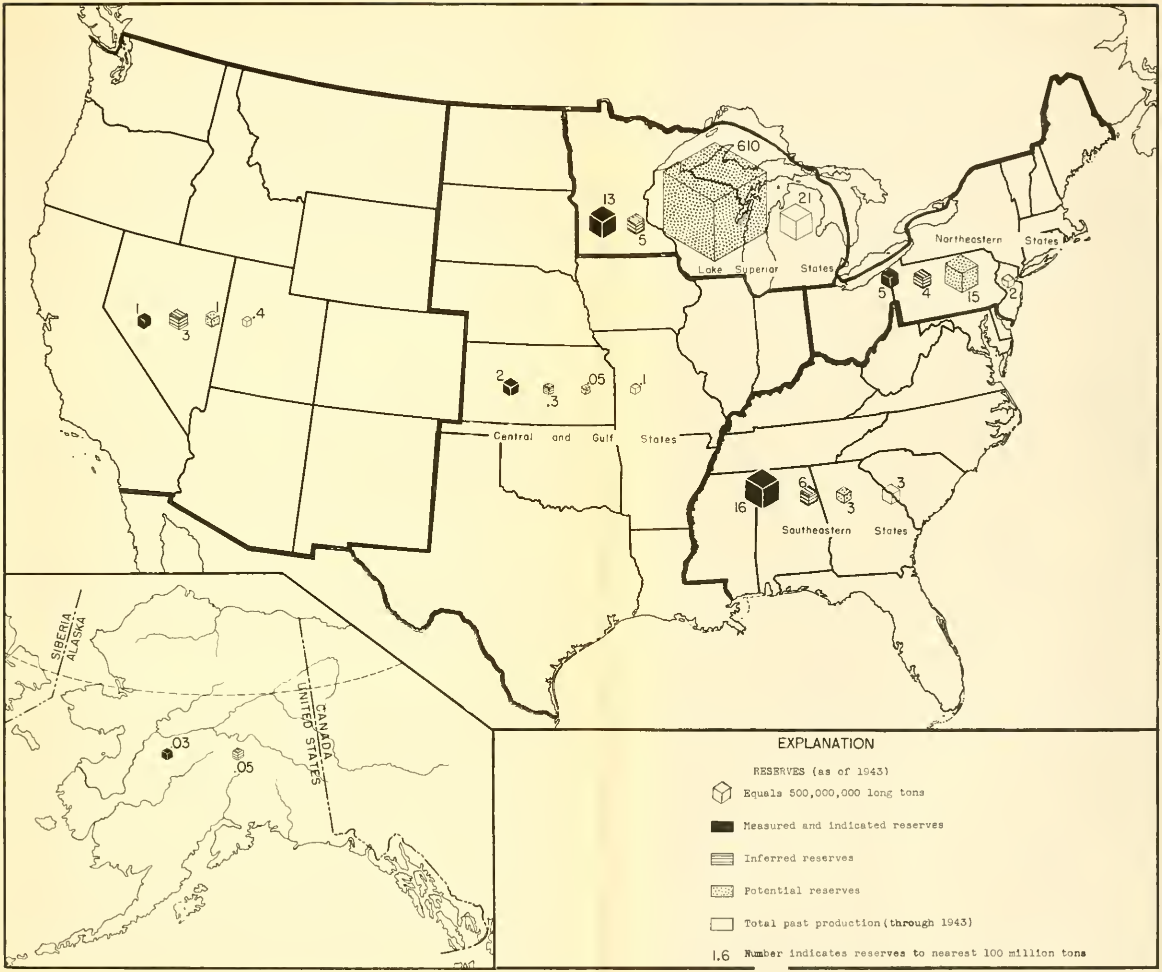


CHART XII.—Comparison of past production of iron ore with reserves as of 1944, by districts.

Within the United States most of the ore is produced by the companies that consume it. The principal sources (see chart XII) are the hematite deposits in the Lake Superior region of Minnesota, Michigan, and Wisconsin, the hematite and limonite deposits in the Birmingham district of Alabama, and the magnetite deposits in the Adirondack region of New York. The Lake Superior region furnishes about 80 percent of the iron ore produced annually in the United States, or an annual average of 50 to 80 million tons, and the Mesabi range alone, in northeastern Minnesota, produces more than half of the total annual domestic production. Most of the largest mines in the United States are on the Mesabi range, and over half of the production is from open-pit mines. The Birmingham district produces 3 to 6.5 million tons annually, almost entirely from underground mines. In the Adirondack region, mines near Lake Champlain have produced ore for many years. Utah, Wyoming, and New Mexico have yielded significant production for the iron and steel plants at Provo, Utah, and Pueblo, Colo., and recently there has been enlarged production from California for the new plant at Fontana, Calif. Small deposits are present in most States. Table 20 shows the output from the major producing States since 1939.

TABLE 20.—*Production of iron ore and concentrates in the United States by principal producing States and percentage of total produced in each, 1939–44*

Year	Minnesota		Michigan		Alabama		Wisconsin		All others		Total, gross tons
	Gross tons	Percent of total	Gross tons	Percent of total	Gross tons	Percent of total	Gross tons	Percent of total	Gross tons	Percent of total	
1939	31, 547, 701	61. 0	9, 159, 222	17. 7	5, 960, 507	11. 5	972, 685	1. 9	4, 091. 615	7. 9	51, 731, 730
1940	47, 736, 810	64. 8	12, 472, 448	16. 9	7, 316, 127	9. 9	1, 262, 065	1. 7	4, 908, 449	6. 7	73, 695, 899
1941	62, 750, 907	67. 9	14, 671, 192	15. 9	7, 884, 851	8. 5	1, 436, 233	1. 6	5, 666, 396	6. 1	92, 409, 579
1942	73, 937, 446	70. 1	15, 624. 161	14. 8	8, 850, 534	8. 4	1, 502, 587	1. 4	5, 611, 467	5. 3	105, 526, 195
1943	69, 084, 907	68. 2	15, 425, 788	15. 2	8, 057, 385	8. 0	1, 498, 749	1. 5	7, 181, 006	7. 1	101, 247, 835
1944	64, 878, 095	68. 9	12, 826, 240	13. 6	6, 829, 437	7. 3	1, 406, 985	1. 5	8, 176, 948	8. 7	94, 117, 705

Many of the deposits of the United States, including some of those in the major districts, include large quantities of material either too poor in iron or containing such a large proportion of impurities that they cannot be used under present economic or technologic conditions. The present trend indicates continued development of the major districts and the probable increase in treatment of the lower-grade and impure ores in them. Many of the deposits in the Western States contain so much sulfur as to make their usability a technologic problem. Iron ore is imported largely from Brazil, Canada, Chile, Cuba, northern Africa, Norway, and Sweden. The steel plant at Sparrows Point, Md., is normally operated largely on ore from Cuba and Chile.

Reserves

Table 21 shows the iron-ore reserves of the United States as segregated into (1) material of such nature and geographic and geologic distribution as to be considered usable under 1944 economic and technologic conditions, in columns headed "Measured and indicated," and "Inferred," and (2) material that may become usable under future conditions, in some cases remote, in the column headed "Potential." The potential reserves include (*a*) material of lower grade than is now mined in the several districts, (*b*) deposits of minable grade but in beds too thin to be minable under present practices, (*c*) deposits containing impurities in harmful quantities, and (*d*) deposits too remote from transportation and blast furnaces for present use.

The grade of iron ore mined depends in large degree upon local conditions, both as to source and technology, and in some districts significant quantities of material are mined that would be considered subgrade elsewhere. Table 21 shows the lowest grade of material commonly mined in the several regions for which reserves are calculated. For Alaska, from which there has been no production, the cut-off grade for ore has been assumed at 50 percent.

The total of nearly 4,000,000,000 tons of measured and indicated ore implies an assured reserve equivalent to 40 years' supply, even at wartime expanded rates of production. It is believed that virtually all this ore can be mined at

65882—47——17

prevailing or somewhat higher prices. The total reserves of measured, indicated, and inferred ores are equivalent to about twice the total past production.

TABLE 21.—*Reserves of iron ore in the United States as of January 1944, and production through 1943*

[In millions of long tons]

Region	Lowest grade of ore commonly mined (percent of iron, natural not dried)	Measured and indicated ore [1]	Inferred ore	Potential ore	Total production through 1943
Lake Superior	51.5	1,306	500	61,000	2,076
Southeastern	35	1,561	560	270	325
Northeastern	25	536	390	1,500	163
Western	50	141	275	140	38
Central and Gulf	50	179	25	5	11
Alaska		3	5		None
Total		3,726	1,755	62,915	2,613

[1] Data insufficient to estimate separately.

LEAD

By E. F. Fitzhugh, Jr.,[60] E. T. McKnight,[61] and A. L. Ransome[60]

Lead is marketed in four principal grades—Corroding, Chemical, Common, and Antimonial or hard lead; the last-named is an alloy of lead and antimony, produced as a refinery byproduct. Lead is used principally in storage batteries, pigments (including white lead, red lead, and litharge), cable covering, in the building trade in the form of sheets, pipes, traps, calking lead and solder, in ammunition, as foil for packaging, as tetraethyl lead for blending in gasoline manufacture, and in numerous other ways. With the exception of zinc and titanium in some pigments, and a new and limited use of plastics for cable covering, there is no satisfactory substitute for lead, principally because the physical properties and relative cheapness of lead make it unique in its field and encourage its substitution for other materials.

The United States has held a major position in the lead industry of the world for many years as both a producer and a consumer. Production from domestic sources had supplied nearly the entire domestic demand for newly mined lead for many years until the Second World War late in 1939. From 1909 to 1939, inclusive, the United States produced about 35 percent of the total lead production of the world; however, the trend was downward from 1916 on, the proportion of world output having ranged from a high of 49 percent in 1916 to 20 percent in 1938.

Imports were small before 1939. The sharp rise of consumption from a low point of 366,000 short tons in 1938 to the record-breaking level of 942,000 tons in 1941 outstripped the capacity of domestic lead mines. Production rose but in 1941 supplied only 50 percent of the total consumed as compared with 82 percent in 1939. The balance came from rapidly increased imports, which reached the all-time high of 492,000 tons in 1942. As imports and domestic output both exceeded actual needs, a stock pile was early established. Subsequently, imports and domestic output both decreased; in consequence, the stock pile was depleted, and lead has remained in short supply. The six leading countries from which lead has been imported since 1939, named in their order of importance, are Mexico, Australia, Canada, Peru, Newfoundland, and Argentina. Considerably more lead has been imported as pig lead, bars, scrap, and base bullion than as concentrates or ore.

The average long-term price for Common lead at New York has been approximately 6 cents a pound, but during World War II various premium prices above a ceiling price of 6½ cents a pound were paid. Under the premium-price plan the maximum possible payment obtainable by mine owners amounted to 12 cents per pound for the recoverable lead content of the ore or concentrates produced. In

[60] Bureau of Mines.
[61] Geological Survey.

effect and as planned, premiums paid on lead have stimulated zinc as well as lead production, for the operators commonly market both lead and zinc concentrates from the same operation.

The mutual relations of consumption, production, exports, imports, and price of lead from 1906 through 1944 are shown on the accompanying figure 19. Until the advent of Government wartime control, beginning in October 1941, the rela-

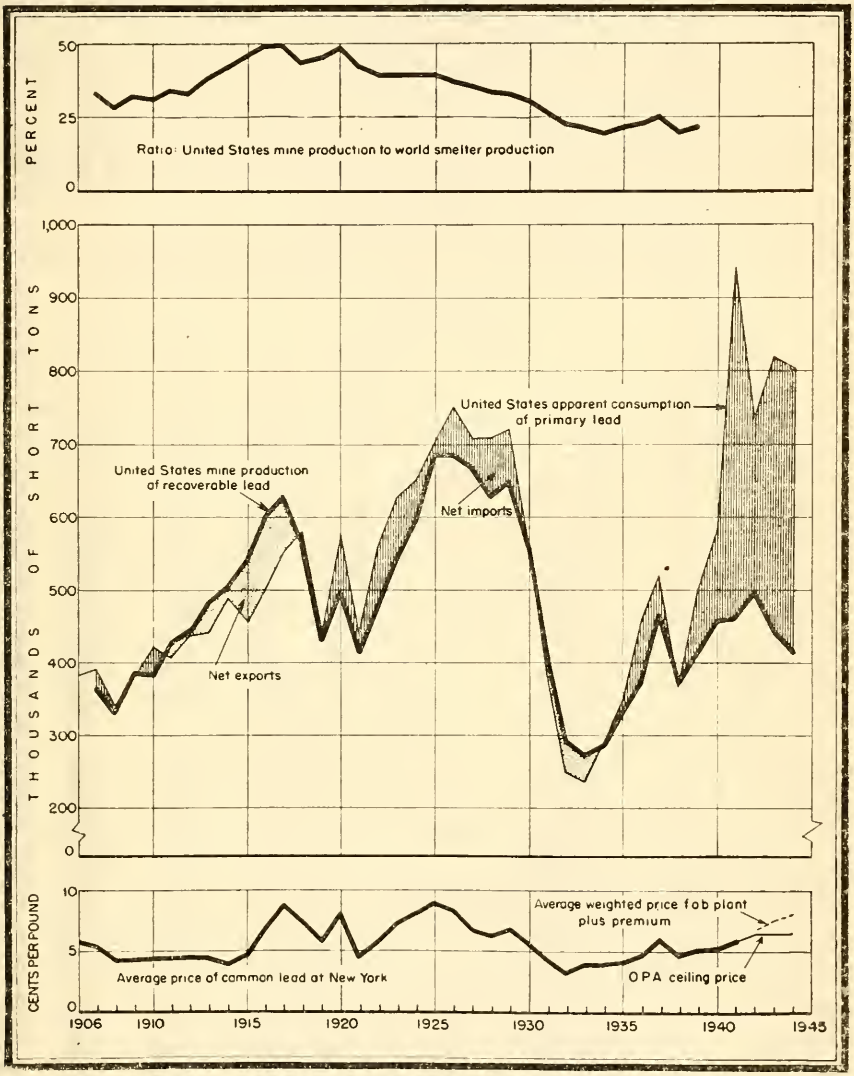


FIGURE 19.—Trends in production, consumption, and price of lead in the United States, 1906–44. Foreign trade includes lead content of ores.

tionship of price, production, and consumption followed conventional patterns, variations in price reflecting changes in production and consumption. In 1942, following the spectacular 3-year increase in consumption, accompanied by only a moderate gain in price and production, the program of lead allocation resulted in a controlled and lower consumption. At the same time, premium prices offered by the Government caused the domestic output to rise slightly. The production of 496,239 tons in 1942 was only slightly above the postdepression high in 1937 and

equaled only 73 percent of the record output of 684,439 tons established in 1925. Despite a substantial rise in the average price paid for lead, including premium payments, production declined to 416,861 tons in 1944, owing largely to manpower shortages at the mines.

There is a large and increasing use of secondary lead recovered as refined lead, antimonial lead, and other alloys from scrap.

Table 22 lists the major producing districts or regions of the United States in the 5-year period from 1940–44. In general, lead is intimately associated with zinc, so that a list of zinc districts includes most of the lead-producing districts. The outstanding exception is Southeastern Missouri, which has been the principal district in lead production since 1908, but from which a negligible amount of zinc is produced; the ore is mined from low-grade disseminated deposits, containing 2½ to 4 percent of lead. The other important lead-producing area in the Central States is the Tri-State region, where the ores contain considerably less lead than zinc, but where the aggregate lead production is large because enormous ore tonnages are handled. The geologic conditions, insofar as they affect mining, are very similar to those in Southeastern Missouri.

TABLE 22.—*Mine production of recoverable lead in the United States, by districts that produced 1,000 tons or more during any year, 1940–44*[1]

[In short tons]

District	State	1940	1941	1942	1943	1944
Southeastern Missouri region.	Missouri	169,893	164,342	197,291	179,012	169,222
Coeur d'Alene region	Idaho	95,609	95,529	106,474	89,813	76,813
West Mountain (Bingham)	Utah	37,857	34,512	39,996	35,437	31,169
Tri-State region	Kansas, southwestern Missouri, Oklahoma.	35,311	41,080	34,341	34,722	28,059
Park City region	Utah	19,749	19,094	15,278	16,022	11,660
Leadville	Colorado	794	1,112	3,348	4,950	5,752
Tintic	Utah	6,536	9,424	10,176	8,261	5,319
Metaline	Washington	2,495	3,819	4,553	4,581	5,278
Central	New Mexico	3,245	3,902	3,026	3,571	4,428
Austinville	Virginia	[2] 2,285	3,390	1,661	1,700	4,235
Old Hat	Arizona	1,908	2,172	1,801	3,140	4,161
Pioche	Nevada	5,526	6,822	2,764	2,942	4,056
Warren (Bisbee)	Arizona	692	970	813	712	3,497
Warm Springs	Idaho	5,050	5,334	3,783	3,635	3,333
Summit Valley (Butte)	Montana	8,859	8,630	7,206	3,290	3,251
Rush Valley	Utah	4,760	4,168	3,988	3,505	2,901
Pioneer (Rico)	Colorado	1,928	2,525	2,282	2,566	2,826
Coso	California	40	700	755	2,448	2,609
Pima (Sierritas, Papago, Twin Buttes).	Arizona	6	4	11	578	2,445
Heddleston	Montana	50	967	2,290	2,350	2,436
Animas	Colorado	2,471	3,045	2,124	2,657	2,236
Harshaw	Arizona	4,581	5,541	6,132	3,496	2,212
Bayhorse	Idaho	935	1,378	1,644	1,481	2,071
Kentucky-southern Illinois	Kentucky, southern Illinois.	1,860	2 538	2,546	2,199	2,048
Resting Springs	California	870	2,581	4,044	2,938	1,800
St. Lawrence County	New York	1,973	2,100	2,434	2,355	1,644
Magdalena	New Mexico	65	424	864	1,320	1,620
Upper Mississippi Valley	Iowa, northern Illinois, Wisconsin.	453	1,345	908	1,004	1,508
Red Cliff	Colorado	1,412	1,710	2,240	1,761	1,444
Upper San Miguel	do	1,278	1,408	1,716	2,074	1,442
Smelter (Lewis and Clark County).	Montana	1,363	1,527	1,988	2,389	1,364
Big Bug	Arizona	690	594	953	1,145	1,244
Eagle	Montana	4,108	3,294	1,999	1,580	1,128
Wallapai	Arizona	2,304	2,408	1,656	1,392	784
Montana	Montana	955	1,601	1,025	509	569
Ophir	Utah	5,354	1,437	1,623	1,461	365
Cataract	Montana	1,904	355	26	115	59
Barker	do	131	22	1,712	1,633	56
Port Hill	Idaho	1,837	1,537	1,044	316	15
Hog Heaven	Montana	3,588	2,824	614		1

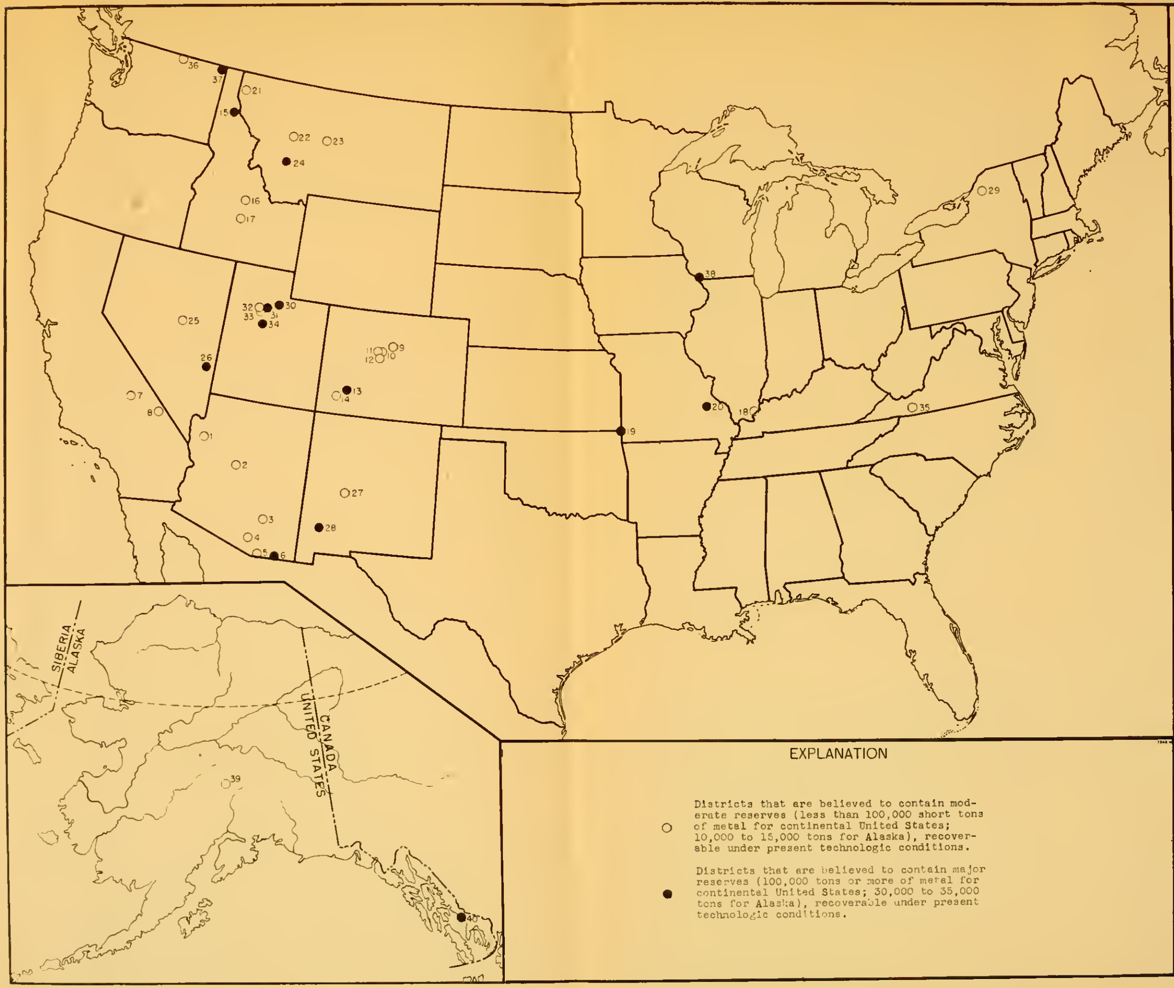
[1] Slightly modified from Minerals Yearbook, 1944.
[2] Total for Virginia, but almost entirely from Austinville district.

The general character, metallic content, and tenor of lead ores of the Western States are discussed in the chapter on zinc. For western lead-zinc ores in general, a combined base-metal content of 10 percent or more, locally including copper as well as lead and zinc, is necessary for profitable mining. In most

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY AND BUREAU OF MINES

LEAD

MINERAL RESOURCES OF THE UNITED STATES



DISTRICTS AND REGIONS
CONTAINING LEAD RESERVES

ARIZONA
1. Wallapai district
2. Big Bug district
3. Mammoth district
4. Pima district
5. Harshaw district
6. Bisbee district

CALIFORNIA
7. Darwin district
8. Resting Springs district

COLORADO
9. Silver Plume district
10. Kokomo district
11. Red Cliff district
12. Leadville district
13. San Juan region
14. Rico district

IDAHO
15. Coeur d'Alene region
16. Bayhorse district
17. Warm Springs district

ILLINOIS
18. Southern Illinois-Kentucky district

KANSAS (-Missouri-Oklahoma)
19. Tri-State region

MISSOURI (-Kansas-Oklahoma)
19. Tri-State region
20. Southeastern Missouri region

MONTANA
21. Troy and Libby districts
22. Heddleston district
23. Barker district
24. Butte district

NEVADA
25. Eureka district
26. Pioche district

OKLAHOMA (-Kansas-Missouri)
19. Tri-State region

NEW MEXICO
27. Magdalena district
28. Central district

NEW YORK
29. St. Lawrence County

UTAH
30. Park City district
31. Bingham district
32. Rush Valley district
33. Ophir district
34. Tintic district

VIRGINIA
35. Austinville district

WASHINGTON
36. Oroville-Nighthawk district
37. Metaline district

WISCONSIN (-Illinois-Iowa)
38. Upper Mississippi Valley district

ALASKA
39. Mt. Eielson district
40. Wrangell district

CHART XIII.—Distribution of reserves of lead in the United States and Alaska as of January 1944, by districts and regions.

districts the zinc content of the ore exceeds that of the lead; but in some districts, particularly in Utah, the relative proportion of these two metals are reversed. Silver is an important byproduct in most western lead-producing districts. Ores containing the higher ratios of lead to zinc are likely to be richer in silver than the predominantly zinc ores; in consequence, a lower base-metal content can be mined profitably.

In Alaska virtually all the lead so far produced has been a byproduct of low-grade gold ores from the Alaska-Juneau mine, which contain only 0.023 percent of lead. Subordinate lead is also present in several of the zinc deposits; the quantity is usually less than 2 percent, but the deposits at Mount Eielson in the Alaska Railroad belt contain 3 to 5 percent of lead and 5 percent of zinc. These deposits are not yet worked.

Reserves

In the chapter on zinc a number of problems that prevent an accurate estimate of reserves are discussed. Because of the intimate association of the two metals, the same limitations apply to estimates of lead reserves. As with the zinc estimates, it has been necessary to include a relatively large quantity of inferred ore in estimates of potential lead supplies.

The existing technology for recovery of lead is so efficient and universally applicable that no significant reserves remain unexploited because of technologic difficulties. The lead reserves available under present technologic conditions are listed in the following categories: (1) Reserves that could be mined under normal economic conditions as reflected in the prices of lead and associated metals, particularly zinc, in relation to production costs ("6-cent lead" and "6-cent zinc" in the 20-year period, 1921–40); (2) additional reserves that could be mined only under more favorable economic conditions, assuming a cost-price spread somewhat better than normal; and (3) additional reserves that could be mined only under abnormal conditions similar to those of 1942–44, wherein the higher premiums for both lead and zinc were paid to operators of deposits of this class. As lead is the subordinate constituent in many base-metal ores, the price of the major constituent, usually zinc, will have a large effect on the quantity of lead mined. The price of silver also will be a critical determining factor in the exploitation of many lead-producing properties.

Table 23 summarizes these estimated reserves, and chart XIII shows their geographic location. Probably 6.2 million short tons of lead—measured, indicated, and inferred—is in ore that can be mined under normal economic conditions. An additional 1.3 million tons is available in ore that should be workable under more favorable economic conditions. The quantity of lead that could be mined only at wartime premium prices is believed to be small, although it is realized that there may be a large tonnage of low-grade material available in Southeastern Mis-

TABLE 23.—*Estimated lead reserves of the United States as of January 1944*

[In short tons of metallic lead]

	Measured and indicated [1]		Inferred		Total	
	Gross content in ground	Recoverable content [2]	Gross content in ground	Recoverable content [2]	Gross content in ground	Recoverable content [2]
A. Lead in deposits that could be mined under technologic conditions as in 1944:						
1. Under normal economic conditions [3]	2, 090, 000	1, 770, 000	4, 120, 000	3, 500, 000	6, 210, 000	5, 270, 000
2. Additional, under somewhat more favorable economic conditions	400, 000	340, 000	890, 000	760, 000	1, 290, 000	1, 100, 000
3. Additional, under emergency prices	110, 000	90, 000	140, 000	120, 000	250, 000	210, 000
Total	2, 600, 000	2, 200, 000	5, 150, 000	4, 380, 000	7, 750, 000	6, 580, 000
B. Lead in deposits whose exploitation is dependent on future technologic advances					Nil	

[1] This includes estimates of measured and indicated ore in some properties where such ore is known, but for which the tonnage figures are unavailable to us.
[2] Milling and smelting losses are considered to be roughly 15 percent.
[3] Price equivalent to 6 cents per pound for both lead and zinc, and prewar costs.

souri about which insufficient information is available for quantitative estimates. A considerable tonnage of lead contained in the low-grade zinc ores remaining in parts of the Tri-State region may never be recovered if this ore is not mined during the period of favorable metal prices following the war.

The estimate does not include inferred reserves in districts not yet discovered, or in known districts the lead potentialities of which have not yet been realized. Hence the estimate is a minimum that will undoubtedly be augmented by such factors to an unknown extent.

The Alaskan reserves, which as known at present amount to only 36,000 tons of metal, indicated and inferred, in all categories of ore, are not included in table 23.

Without regard for price and productive capacity, the lead recoverable from measured and indicated ore by present technologic methods is equivalent to the domestic needs of this country for 4 years at an estimated minimum peacetime rate of 500,000 tons of primary metal per year. The additional inferred reserves in known districts should add another 9 years. At an annual wartime demand of about 750,000 tons, the total reserve is equivalent to only a 9-year supply. However because domestic lead-producing capacity is not rapidly adjustable to sudden increases in demand for the same reasons that make zinc production equally unadjustable, it would appear probable that, unless a huge stock pile is built up, heavy dependence will be placed on foreign sources in any future war period. The lead deposits of Mexico appear ample to supply a large share of such needs.

Magnesium Raw Materials

By Eugene Callaghan [62] and C. L. Harness [63]

Magnesium metal, magnesia refractories, and magnesium salts are obtainable from several mineral sources. Before World War II, magnesium metal was produced exclusively by the electrolysis of magnesium chloride, in only one plant, which recovered magnesium chloride and various other salts from underground brines in Michigan. The tremendous increase in demand for this metal just before and during the war necessitated rapid expansion of production capacity; this resulted in the construction of plants that used other raw materials, including sea water, dolomite, magnesite, and residues from potash manufacture. The war demonstrated the technical feasibility of using numerous minerals for magnesium production; but it now appears that sea water and underground brines, which yield other chemical byproducts, will be the most economical sources for some time to come. The uses of magnesium metal are expanding rapidly, and it is being substituted for other metals.

A much larger use of magnesium minerals is in refractories for basic open-hearth steel furnaces; dolomite (magnesium-calcium carbonate) and high-magnesian limestones supply the bulk of this use. More specialized refractories are made from magnesite (magnesium carbonate), brucite (magnesium hydroxide), and magnesia recovered from sea water and brines. Olivine (magnesium silicate) is used as a slag lime refractory in the steel furnace. Magnesia refractories for the sides and bottoms of open-hearth furnaces have no satisfactory substitutes and are even gradually displacing neutral and silica refractories in the furnace sides and roofs.

Magnesia calcined at lower temperatures than refractory magnesia is more reactive than the latter and has different uses, such as in oxychloride cement flooring for factories and ship decks, in fertilizer to remedy magnesium-deficient soils, in making neoprene rubber, and in milk of magnesia. No substitute for magnesium plant foods has so far been found, but the function of magnesia medicinals may well be duplicated in other remedies. Flooring compositions have been developed which compare favorably with magnesia oxychloride cement.

Magnesite is the main source of both refractory and reactive magnesias and is currently mined at Chewelah, Wash.; Gabbs, Nev.; and Llano, Tex. That in Washington is calcined exclusively for refractory purposes. Nevada magnesite is calcined for numerous chemical uses, and Texas magnesite is calcined for fertilizer. Purer magnesia for refractories is recovered from sea water in California and New Jersey, and one California sea-water plant produces only the purest types of magnesia for medicinal, rubber, and other high-specification uses. Brucite is mined at Gabbs, Nev., and calcined for refractory use. Underground

[62] Geological Survey.
[63] Bureau of Mines.

brines in Michigan are sources of both magnesia and magnesium carbonate for refractory and chemical uses. Dolomite is processed directly in several Eastern States and in California for its magnesia content, which is recovered as a basic carbonate or as a lime-rich magnesia. Dolomite is also used in conjunction with most brine and sea-water processes as an additional source of magnesium. Natural magnesium salts, such as the chloride and sulfate, are obtained from underground brines in Michigan and from sea-water bitterns in California. Magnesium sulfate is used as a rayon-filament coagulant and in the manufacture of epsom salt. During the past few years, fertilizer-grade magnesium sulfate has been obtained from olivine and serpentine.

Magnesium metal was made from all of the commercial magnesium-bearing minerals except olivine, serpentine, and brucite during World War II. Production capacity rose from 6,500 short tons in 1940 to 293,000 tons annually by the end of 1943. Production increased from 5,325 tons in 1939 to 183,584 tons in 1943 but declined to 32,792 tons in 1945 and about 5,000 tons in 1946. Thus, by 1943, capacity exceeded wartime consumption, and a reduction of more than 35 percent took place even before the war ended. After the war all the metal-producing plants except the original producer in Michigan shut down; however, in July 1946 a Texas plant recovering magnesium from sea water was reopened. A plant in California which recovered magnesia from sea water for reduction to metal has continued its magnesia unit for the manufacture of refractories. Indications are that postwar production of magnesium metal, although of much smaller magnitude than wartime output, will exceed prewar production by a substantial margin because of new uses developed during the war. Magnesium alloys were substituted for aluminum alloys where saving of weight was imperative.

Before the war the United States was virtually self-sufficient in all grades of magnesium compounds except a type of dead-burned magnesite imported from Austria and Manchuria, used in making magnesia brick for the open-hearth steel furnace. In the 5-year period 1935–39 domestic magnesite output averaged 177,000 short tons and was supplemented by average annual imports of 82,000 tons (magnesite equivalent). Nearly all the imports were brick grade. The only brick-grade magnesia then available in the United States was obtained from sea water at a California plant. Research has since indicated that brick-grade magnesia could be produced from the large magnesite deposits at Chewelah, Wash., and a flotation mill went into operation there at about the time the war cut off receipts of Austrian and Manchurian brick-grade magnesite. It now appears that the United States can be independent of foreign magnesium mineral supplies.

Of the minerals processed in 1945 to yield magnesium compounds, sea water was the most important, furnishing directly 176,750 short tons of magnesium compounds, principally magnesium chloride. Magnesite was next, with 149,084 tons of compounds, followed by dolomite 65,815 tons, well brines 55,565 tons, brucite 50,153 tons, and serpentine 1,111 tons. Dead-burned dolomite used as an open-hearth dressing is excluded here; over 1,000,000 tons is consumed annually for this use.

Reserves

Reserves of sea water and underground brines, the present commercial source of metallic magnesium, are virtually inexhaustible. Consequently the reserve position of the United States with respect to metal production is most favorable.

Reserves of all of the other magnesium minerals are also very large; but deposits of high-grade material, easily extracted and accessible to industrial areas, are rather limited. Magnesite reserves are less plentiful than those of the other magnesium minerals (except brucite, which is commercially relatively scarce). About 8,000,000 tons of usable magnesite, occurring in Washington and Nevada, is available for open-pit mining and may be considered as measured ore. Probably 85,000 tons of impure magnesite, in the same States, may be considered inferred ore. In terms of 1941 consumption, these reserves would furnish magnesia refractories for about 250 years.

A number of dolomite deposits of commercial grade have been investigated recently and are inferred to contain 136,000,000 tons. This amount is regarded as representing but a small part of the total high-grade dolomite that may be available.

Deposits of olivine and serpentine on both the Atlantic and Pacific coasts contain almost astronomic amounts of magnesium, but technical difficulties have

deterred commercial utilization. During the past few years a small Georgia plant has been recovering magnesium sulfate from serpentine, and recent research indicates that magnesium salts may be economically recovered from olivine also. Continued research may eventually classify these magnesium silicates as major magnesium raw materials.

Manganese

By Max D. Crittenden, Jr.,[64] Thomas A. Hendricks,[64] Albin C. Johnson,[65] and Norwood B. Melcher [65]

The most important use of manganese is in steel making, where it is employed chiefly in the form of ferromanganese, as an alloying metal, and as a purifying agent. Manganese imparts hardness to iron and therefore is used in many varieties of steel. Because its affinity for oxygen and sulfur is greater than that of iron, manganese is added to the molten metal to facilitate the removal of these objectionable impurities from steel. About 95 percent of the manganese consumed in the United States is used in the steel industry and 5 percent in the manufacture of dry batteries and chemicals. There are no satisfactory substitutes for manganese in its important uses.

The United States depends largely on imports for its supply of manganese ore, less than 10 percent of its requirements being obtained from domestic sources. In the 5 years preceding World War II, the average annual apparent consumption of manganese ore was approximately 675,000 long tons, whereas domestic production averaged only 30,000 tons. Under the stimulus of high prices and lower specifications, domestic production has increased appreciably during the last two wars. From 1915 to 1918, the output rose from 10,000 to 306,000 tons, the latter amount representing over a third of the total demand in that year. Similarly, in 1944, production advanced to 250,000 tons, but this was less than a fifth of total requirements. Production during the recent war was handicapped by the fact that many of the readily available deposis of higher-grade ores had been exhausted. Figure 20 shows trends in the production, consumption, and price of manganese ore in the United States and world production from 1910 to 1944.

The United States obtains manganese ore from several sources, the principal ones being Gold Coast, Soviet Union, Cuba, British India, Brazil, and Chile.

The increase in peacetime demands, from an average of about 200,000 tons in the early 1900's to 675,000 tons in the few years before the war, is likely to continue, although at a progressively lower rate. Average annual consumption for the next 20 years probably will exceed 750,000 tons. During the war, when annual production of steel rose to 90,000,000 net tons, consumption of manganese ore was over 1,300,000 long tons annually. The small amount contributed to meet this demand by domestic production can be expected to increase only to the degree that processes of extraction used under the high wartime price prove economic at lower price levels, and to the extent that processes for recovering the manganese from very low-grade material can be developed and applied at a cost comparable to the price of imported high-grade ore. Electrolytic manganese is beginning to displace ferromanganese in the manufacture of stainless steel and may displace low-carbon and medium-carbon ferromanganese in many special alloy and low-carbon steels in which the cost of the manganese is a small item. Production of the metal on a considerably larger scale than at present, with resultant lower costs of production, could expand the use of electrolytic manganese.

Reserves

Manganese is widely distributed in nature. Mineralogical occurrences have been reported in numerous places and in virtually every State. However, no deposits comparable in size and grade to those found in the principal producing countries of the world have been discovered in the United States. Several small deposits of higher-grade material that could be used directly or converted to usable grade by simple concentration methods have been found; but as previously stated, most of them have been exhausted. The United States does possess several large deposits of low-grade material which in the aggregate contain very large quantities of manganese that could be recovered under improved technology, higher prices, or both. Chart XIV shows the distribu-

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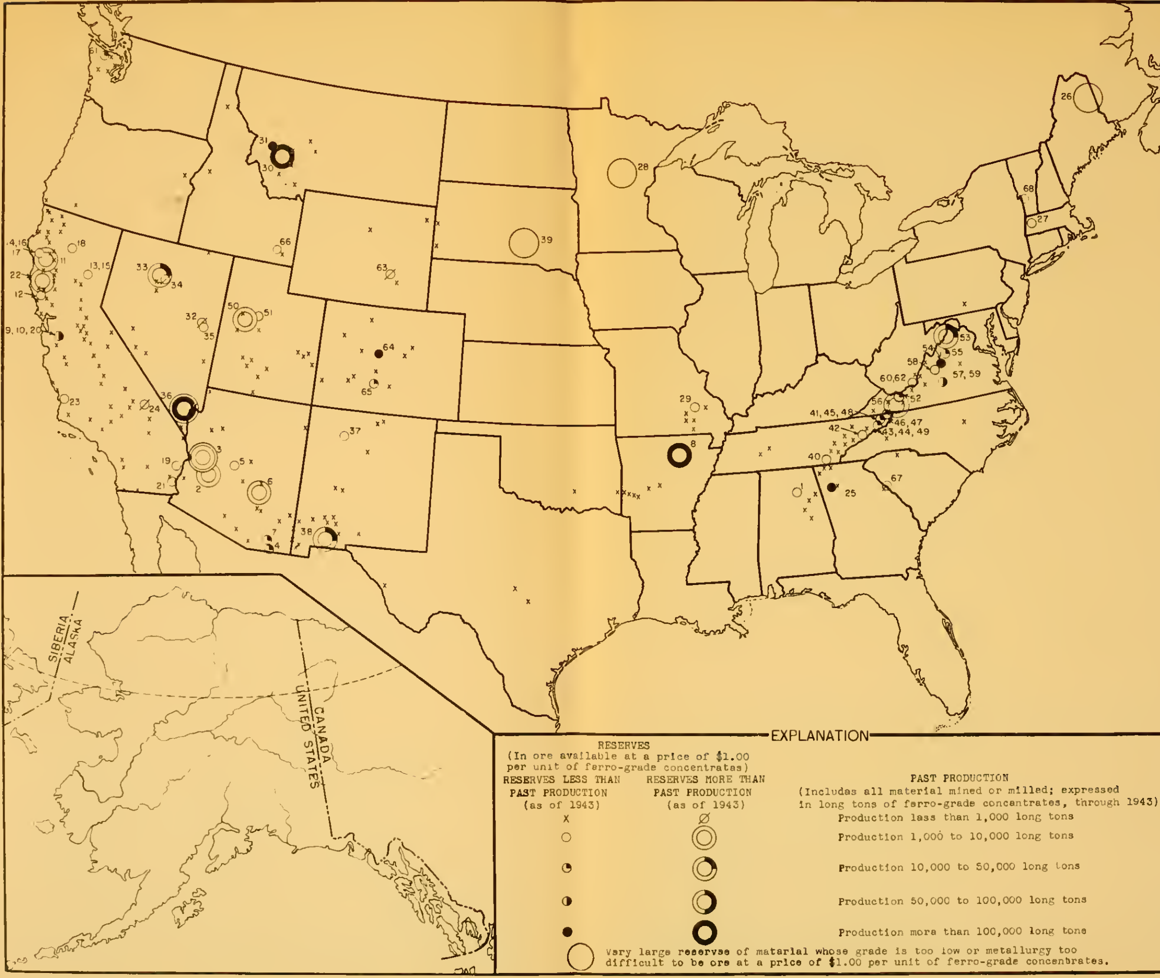
[64] Geological Survey.
[65] Bureau of Mines.

MANGANESE



LIST OF MANGANESE LOCALITIES

List of deposits with production or reserves of more than 1,000 long tons of ferro-grade concentrates.

ALABAMA	1. Walnut Grove district
ARIZONA	2. Aguila district
	3. Artillery Peak district
	4. Bisbee district
	5. Burmeister
	6. Globe district
	7. Tombstone district
ARKANSAS	8. Batesville district
CALIFORNIA	9. Arroyo Mocho district
	10. Black Wonder district
	11. Blue Jay
	12. Boyer
	13. Braito
	14. Charles Mountain
	15. Crystal Lake
	16. Fort Baker
	17. Fort Seward
	18. Beroult
	19. Ironwood district
	20. Ladd-Buckeye district
	21. Paymaster district
	22. Thomas
	23. Welch
	24. Wingate Wash
COLORADO	64. Leadville district
	65. Pershing
GEORGIA	25. Cartersville district
IDAHO	66. Vanza
MAINE	26. Aroostook County
MASSACHUSETTS	27. Taconic
MINNESOTA	28. Cuyuna Range
MISSOURI	29. Cuthbertson
MONTANA	30. Butte district
	31. Philipsburg district
NEVADA	32. Black Devil
	33. Black Diablo
	34. Black Rock
	35. Nevada district
	36. Three Kids district
NEW MEXICO	37. Cuba district
	38. Little Florida Mountains
SOUTH CAROLINA	67. McCormick
SOUTH DAKOTA	39. Chamberlain district
TENNESSEE	40. Bradley County
	41. Butler district
	42. Cocke County
	43. Embreeville district
	44. Hampton district
	45. Holston Mountain district
	46. Mountain City district
	47. Shady Valley district
	48. Stony Creek district
	49. Unicoi district
UTAH	50. Drum Mountains
	51. Tintic district
VERMONT	68. South Wallingford
VIRGINIA	52. Bland County
	53. Cedar Creek Valley district
	54. Crimora
	55. Elkton district
	56. Glade Mountain district
	57. James River district
	58. Lyndhurst-Vesuvius district
	59. Roanoke River district
	60. Sweet Springs district
WASHINGTON	61. Crescent mine
WEST VIRGINIA	62. Sweet Springs district
WYOMING	63. Poverty

CHART XIV.—Distribution of past production and reserves of manganese ore in the United States as of 1943, by districts.

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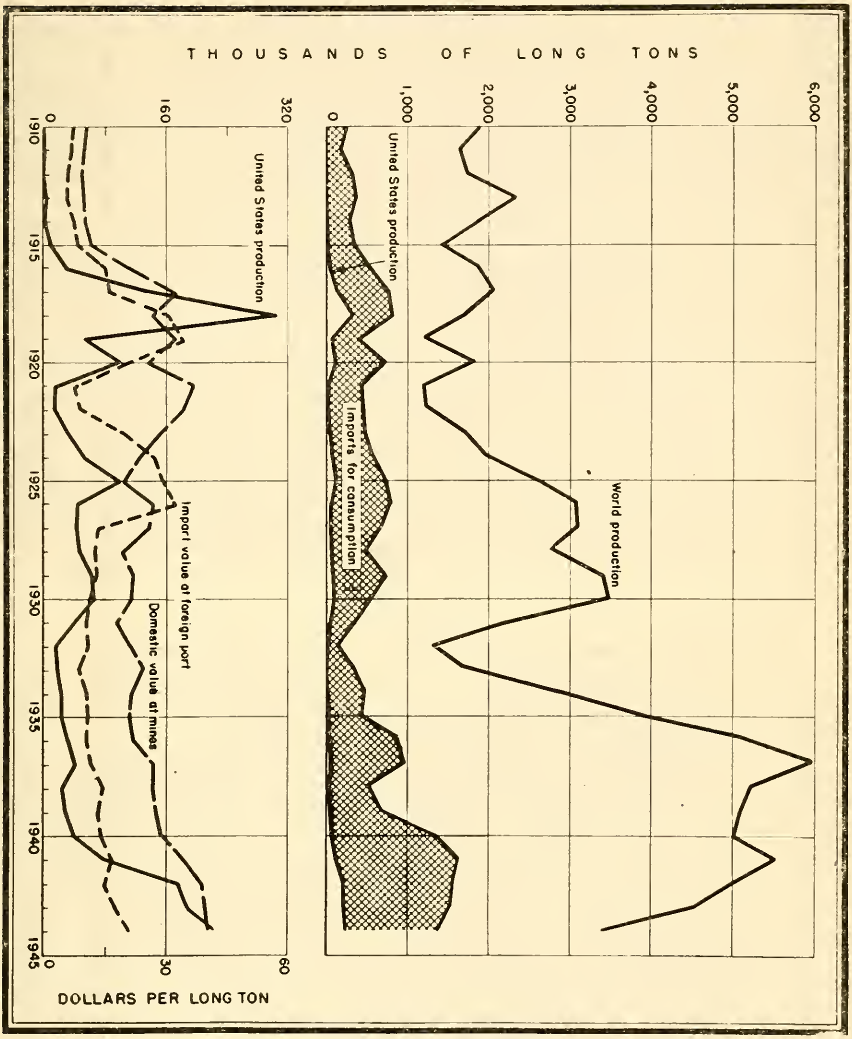

FIGURE 20.—Trends in production, consumption, and price of manganese ore in the United States and in world production, 1910–44.

tion of domestic manganese ore deposits whose past production or reserves, as of 1943, were equivalent to more than 1,000 long tons of ferrograde material.

TABLE 24.—*Estimated reserves and probable rate of production of manganese in the United States*

Assumed conditions: General	Assumed conditions: Price per unit	Reserves (tons of metallic manganese)	Possible annual production rate (tons of ferrograde)
Average peacetime conditions with technology as in 1944.	$0.50 and less	500,000	Maximum of 25,000.
Wartime conditions similar to 1944	$1	2,000,000 [1]	200,000 to 250,000.
Conditions of dire need, price no object.	$2±	50,000,000 to 75,000,000	To fill requirements.

[1] Under normal peacetime conditions, with the improvements that have been made and further improvements that will be made in the next decade in the technology for treating low-grade manganese ores, it is not unreasonable to expect that this reserve might become available at a price range of 50 to 75 cents per unit.

Table 24 gives estimates of the reserves and probable rate of production of manganese in the United States under various economic and technologic assumptions. It is estimated that there are, in the United States, about 10,000,000 long tons of material of such nature, grade, and availability that it can be treated under the special arrangements and prices established by the Metals Reserve Company during the war. These included a base price of $1 per long-ton unit for ore containing 48 percent or more of manganese. Approximately 2,000,000 long tons of metallic manganese could be recovered from this reserve. Most of the ore is in four districts—Butte and Philipsburg, Mont.; Three Kids, Nev.; and Batesville, Ark. Other deposits are in the Cartersville district of Georgia, and in Virginia, California, New Mexico, Tennessee, Utah, Arizona, and Washington. The present outlook for technologic improvement indicates that this reserve might become available at 75 cents a unit or less within a decade. Were the price of manganese to drop from $1 a unit to the long-term average of less than 50 cents, the reserves of available material probably would not exceed 500,000 tons of metallic manganese.

In addition to the limited amount of manganese recoverable at $1 a unit or less, several hundred million tons of low-grade material is available, containing 1 to 10 percent manganese, from which manganese could be obtained by known processes at high costs. The manganese content in these resources equals 50,000,000 to 75,000,000 tons, which would be adequate to supply domestic needs for many decades if it could be made available economically. The deposits included in this group are found in the Cuyuna range, Minn.; eastern Aroostook County, Maine; Artillery Peak district, Arizona; Chamberlain, S. Dak.; and the Three Kids district, Nevada. The Cuyuna reserves, consisting of manganiferous iron ore, which is now used in the production of manganiferous pig iron and spiegeleisen, probably will continue to be used for this important purpose.

Mercury

By Edwin B. Eckel,[66] Helena M. Meyer,[67] and McHenry Mosier[67]

Peacetime production of mercury in the United States is controlled by world mercury prices, with significant lags to be expected between price increases or decreases and resultant increased or decreased production.

The war uses of mercury include pharmaceuticals, catalysts in connection with chemical warfare, fulminate for detonating high explosives, antifouling paint for ship bottoms, dental amalgams, electrical apparatus, barometers, gages, other instruments, and calomel for tracer bullets. As a result of the development of a new dry-cell battery, an important component of which is mercuric oxide, in the latter part of World War II, an enormous increase in wartime consumption of mercury was in prospect; the expected requirements for this purpose promised to surpass all others combined. Civilian uses for mercury include all of the above, except the tracer-bullet use, with the future of the new battery subject to research and development work. In addition, mercury is employed for agricultural purposes, in amalgamation of gold ores, in boilers for the generation of power, in vermilion pigment, and in other applications. Almost all uses, except in boilers and possibly in the new batteries, result in loss or dissipation of the mercury so that little can be recovered for reuse.

In the pharmaceutical field substitutes for mercury include sulfa drugs, iodine, and other antiseptics and disinfectants. Lead oxide and organic initiators, such as diazo-dinitro-phenol, are used as substitutes for mercury fulminate and are preferred by some. Tetryl and nitromannite are also incorporated in some detonators, so that the demand for mercury fulminate is correspondingly diminished. The use of detonating fuse has reduced the requirements for blasting caps and consequently for mercury fulminate. Plastic paint and copper-oxide paint are used for the protection of ship bottoms. Metal powders and porcelain replace mercury for some dental uses. For some agricultural uses copper compounds, formaldehyde, and other products can be substituted for mercury. Other processes are available to replace the mercury used in electrolytic reduction or as a catalyst. There are thus relatively few uses for which no substitutes could be developed under sufficient stress. Relative costs, efficiency, and industrial habit, however, will prevent large-scale substitution until mercury becomes much more scarce than it is at present.

The greater part of the world's mercury deposits occur in a zone bordering the Pacific or are along the northern edge of the Mediterranean. A few deposits are

[66] Geological Survey.
[67] Bureau of Mines.

explored to a depth of 1,000 to 2,500 feet, but most extend only a few hundred feet. Most deposits are roughly veinlike in form, though notably discontinuous and irregular in grade and shape. Few individual bodies are more than 100 to 200 feet in any dimension and most can be measured in tens of feet. Cinnabar is the only valuable mercury mineral in virtually all commercial deposits.

As shown in figure 21, the annual domestic production, which has ranged from 6,000 to 52,000 flasks (of 76 pounds) since 1910, has rarely equaled the demand,

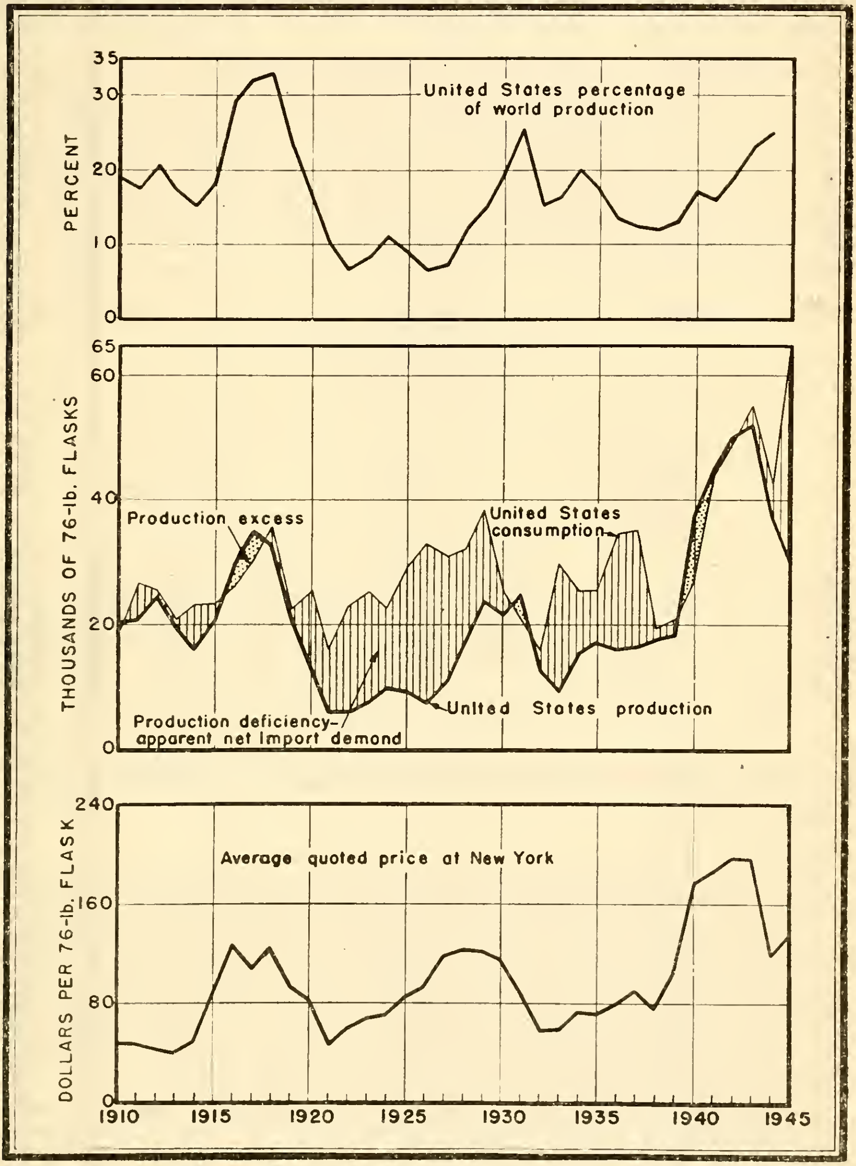

FIGURE 21.—Trends in production, consumption, and price of mercury in the United States, 1910–44.

and the deficiency has been met by imports from Spain, Italy, and other countries. Spain and Italy dominate the world production of mercury and under normal conditions supply at least 80 percent of the total. Under prewar conditions, the price of mercury and hence the American production rate was controlled largely

by the Spanish and Italian industries because their large bodies of high-grade ore have produced mercury at lower costs than most of the United States mines could meet. Figure 21 shows the close relation between price and production in the United States.

Reports as to the extent of the Spanish and Italian reserves are conflicting, but those countries probably will be able to maintain production at fairly high rates for many years. The Soviet Union too probably has large reserves, as has Mexico, although most of the Mexican mines can be worked only during periods of high prices. China, Japan, Peru, and a few other countries produce mercury in minor amounts.

The Coast Ranges have led the United States in production of mercury since 1845. California has produced 89 percent of the total United States production, most of it from a few great mines that were discovered in the early days of the West and have been constant producers ever since. During the period 1940–44 California produced 61 percent, Oregon 15 percent, Nevada 10 percent, and Idaho 5 percent of the United States total. Arkansas and Texas also produced significant amounts, and some mercury has come from Arizona, Washington, Utah, and Alaska. The future geographic trend of domestic production is indicated by the estimates of reserves in table 25 and chart XV, which show the distribution of past production and commercial reserves of mercury.

TABLE 25.—*Estimated mercury reserves of the United States, including Alaska, as of January 1944, by States*

[In flasks of 76 pounds]

State	Workable at $100 a flask			Workable at $195 a flask [2]			Workable at $300 a flask [2]		
	Measured and indicated [1]	Inferred	Total	Measured and indicated [1]	Inferred	Total	Measured and indicated [1]	Inferred	Total
Alaska	300	300	600	9,500	14,200	23,700	14,500	30,200	44,700
Arizona		500	500	3,500	3,500	7,000	3,500	3,500	7,000
Arkansas				200	3,500	3,700	200	3,500	3,700
California	31,000	34,000	65,000	72,400	107,400	179,800	90,300	160,600	250,900
Idaho		1,000	1,000	14,300	3,700	18,000	34,000	5,400	39,400
Nevada	5,400	8,000	13,400	25,000	50,000	75,000	29,000	75,000	104,000
Oregon	3,500	1,000	4,500	10,000	6,800	16,800	13,000	7,800	20,800
Texas	500	500	1,000	2,500	3,000	5,500	3,000	6,000	9,000
Washington					500	500		2,000	2,000
Total	40,700	45,300	86,000	137,400	192,600	330,000	187,500	294,000	481,500

[1] Separation of "measured" and "indicated" ore is not made because of lack of detailed information at some mines. Ore at most mines is indicated and inferred because measured ore is extracted during development.

[2] Cumulative totals.

Reserves

The reserves of mercury in the United States, as shown in table 25, are larger than many persons believed were available at the beginning of the war. This increase is a direct result of high prices, which stimulated exploration for new ore, and development of it, as well as the exploitation of leaner material. The estimates for ore workable, by individual mines, at $100 a flask assume average peacetime conditions. The estimates for ore workable at $195 a flask are based on emergency conditions as in 1943, and the estimates for ore workable at $300 a flask represent the additional quantity that would become available under extreme emergency conditions. The large quantity of inferred reserves at the higher prices reflects the stimulation of exploration and development that may reasonably be expected at the higher price level.

The estimates include a wide range of cut-off grades. At a price of $195 a flask, some open-cut mines can operate profitably on material that contains as little as 2 pounds of mercury to the ton, whereas some underground mines with difficult operating conditions must have 10-pound ore or better. Most of the material workable only at a minimum price of $195 a flask contains 1 to 2 pounds of mercury to the ton, but that estimated for Alaska is considerably richer. Its ultimate extraction depends on the market price, for no radical reductions in mining or treatment costs are anticipated.

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MERCURY

MINERAL RESOURCES OF THE UNITED STATES

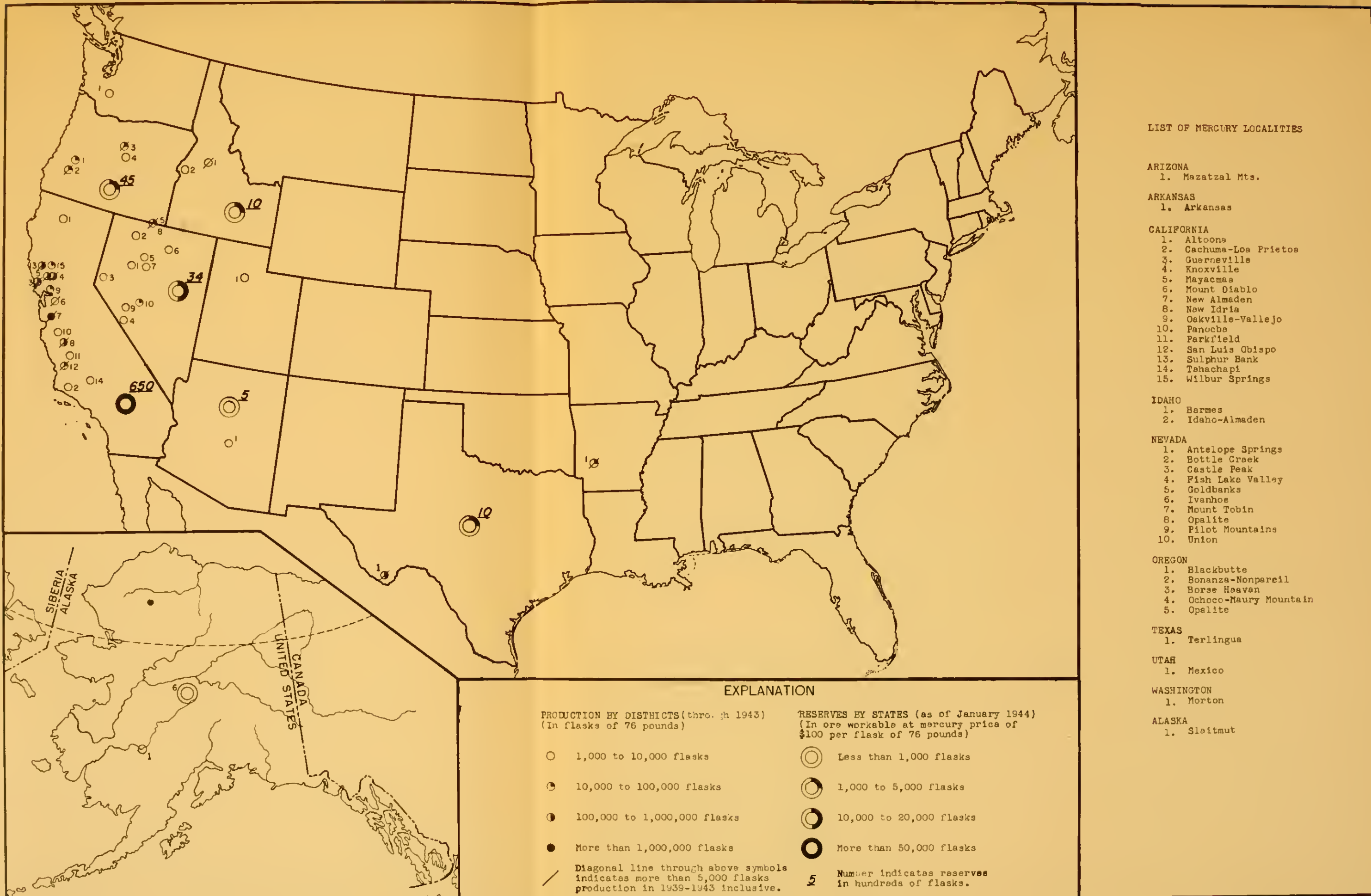

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CHART XV.—Total production through 1943, by districts, and distribution of reserves of mercury in the United States and Alaska, as of January 1944, by States.

The estimates make no allowance for discoveries of ore far beyond present mine openings or of new mercury districts. It is believed that, except in Alaska, the most promising ground has been well-prospected but not exhausted. More ore shoots will eventually be found in known mines and districts, and some mercury-bearing regions that are remote or that have ore bodies with meager surface indications, such as parts of Idaho, Oregon, Nevada, Alaska, and northern California, probably will yield deposits on more thorough exploration.

Production rates, as well as available reserves, are closely related to price. The time lag between increases in price and resultant increases in production ranges from 1 to 3 years, depending on the condition of the mines preceding the increase in price. After a long period of low prices, most mines would be closed, and inasmuch as many would be caved or flooded, they would be unable to resume production without considerable delay and expense.

Strategic Mica

By H. M. Bannerman,[68] E. F. Fitzhugh, Jr.,[69] and G. R. Gwinn[69]

The United States is the world's largest consumer of strategic mica and has depended almost entirely on imports for its supply. Although production during World War II was encouraged by the urgent demand, the mining and preparation of mica require a large amount of hand labor; and it is extremely doubtful, in view of labor costs in this country, that the domestic mica industry can compete in normal times with the low-cost imported material.

Many varieties of mica occur in nature, but only two—muscovite (white mica) and phlogopite (amber mica)—are commercially important. Muscovite of sheet quality occurs mainly in granite pegmatities, especially those in which the predominant feldspar is plagioclase. No phlogopite deposits of commercial grade are known in the United States.

Sheet mica is marketed in a variety of sizes and qualities that currently range in value from a few cents to $12 a pound. The major wartime demand was for material of the size and quality classed as "strategic mica." It consists of sheet or punch mica in rifted condition (split into blocks or sheets 1/100 to ⅛ inch thick), three-quarters to full trim, and at least 1 by 1 inch in size. Also it must be free from black or red stains, cracks, and pinholes; relatively free from clay stains; and also free from defects of crystallization, such as cross grains or reeves (breaks or tears in splitting that produce only partial films) and ribs (waves or ridges in the crystal sheet).

Before 1942 most domestic sheet mica was marketed as half trim (trimmed on two adjacent sides with no cracks extending from the trimmed sides). Sizes less than 1¼ inches in diameter were not accepted as sheet, and most material below 2 inches in diameter was sold as punch. None of it was used for purposes comparable to those for which strategic mica was used during the war. With the advent of war, the demand for high-quality sheet became so urgent that it was necessary for the Government to set aside all strategic-quality mica for allocation, and special measures were adopted to promote the recovery of mica of this quality from domestic deposits. The emphasis in mica mining during the war years, therefore, has been placed upon the production of strategic mica, and sales were based on three-quarters and full-trim material.

The principal strategic uses of sheet mica are in making radio tubes and other communication equipment, magneto condensers, radar equipment, and airplane spark plugs. About 65 percent of the strategic mica used in 1944 was employed in condensers, tubes, and other applications in radio and radar equipment. The remainder was employed in magnetos, spark plugs, gage glass, compass cards, diaphragms, television, and miscellaneous uses.

Ceramics, laminated paper, plastics, and newly developed insulating materials can be substituted for mica in some strategic uses, and advances in technology have made it possible to substitute larger and larger quantities of stained material in applications in which only clear material was previously used, but there is as yet no substitute for high-quality mica. There is no scrap recovery.

Mica has been produced in 25 States, but the major share of the production has come from North Carolina, New Hampshire, Connecticut, South Dakota, Georgia, and New Mexico. (See chart XVI.)

[68] Geological Survey.
[69] Bureau of Mines.

Domestic production, by regions, and for all sizes and qualities of sheet and punch mica for the 30-year period, 1912 to 1941, was as follows:

	Pounds
Southeastern States	22, 182, 120
New England States	15, 566, 400
South Dakota and other Western States	1, 167, 480

The average annual production for the period was 1,300,000 pounds. None of the domestic output in prewar years, however, received the careful grading and trimming that are given to mica of strategic quality; but for comparison, it is estimated that 10 to 15 percent of this past production could have been selected and trimmed to meet today's strategic mica specifications.

Imports come mainly from India, Brazil, Argentina, Madagascar, and Canada.

According to figures compiled by the War Production Board, consumption of sheet and punch mica in the United States in 1943 totaled 4,110,600 pounds, of this amount domestic sources supplied 623,600 pounds. The corresponding figures for 1944 were 3,728,800 and 766,500 pounds, respectively. Accordingly, during the period of its most intense effort the domestic industry furnished only 10 to 15 percent of the wartime domestic requirements. It should be noted, however, that although the United States mica industry produced block mica, it had no experience in the preparation of strategic-quality mica before the war and that at the beginning of 1942 most of the domestic mica mines were closed down. With the experience now gained and with proper preparation, a relatively higher rate of production probably could be attained for a reasonable period.

Figure 22 illustrates the consumption of sheet and punch mica in the United States as measured by imports plus domestic production of strategic grades during the war years.

The average market price of strategic mica in the United States during 1943 and 1944 was approximately $1.50 per pound. The price paid to producers by the Government during the same period was $5 per pound, plus the cost of handling, marketing, and other indirect forms of subsidy. This price was increased to $6 per pound in 1944.

Reserves

There are no measured reserves of mica in the United States. Most of the domestic mines are small and shallow. The practice has always been to mine rich pockets and zones, largely by hand methods, and to abandon a deposit as soon as it became unprofitable. Nearly all the mines have been developed from surface exposures, and little or no development work is undertaken before entering upon production. Because of this piecemeal mining practice, development is tantamount to production.

The industry has no record on which production of strategic mica can be predicted, aside from operations under Government subsidy. Estimates of reserves herein stated are based on prices of $6 per pound for three-quarter to full-trim sheet mica and other conditions comparable to those prevailing in June 1944. Given similar conditions in future the strategic mica recoverable from reasonably assured extensions of known deposits—indicated reserves—probably would total about 2 million pounds, distributed as follows:

	Pounds
Southeastern States	1, 270, 000
New England States	575, 000
South Dakota and other Western States	355, 000

Considering the facts that most mica mines are shallow and the deposits relatively undeveloped, that numerous potentially productive pegmatites have not been explored to any degree, and that the present trend is toward the use of more and more stained material for "strategic" uses, the inferred reserves may reach a total of 30,000,000 to 40,000,000 pounds of strategic mica from the districts established,

MICA

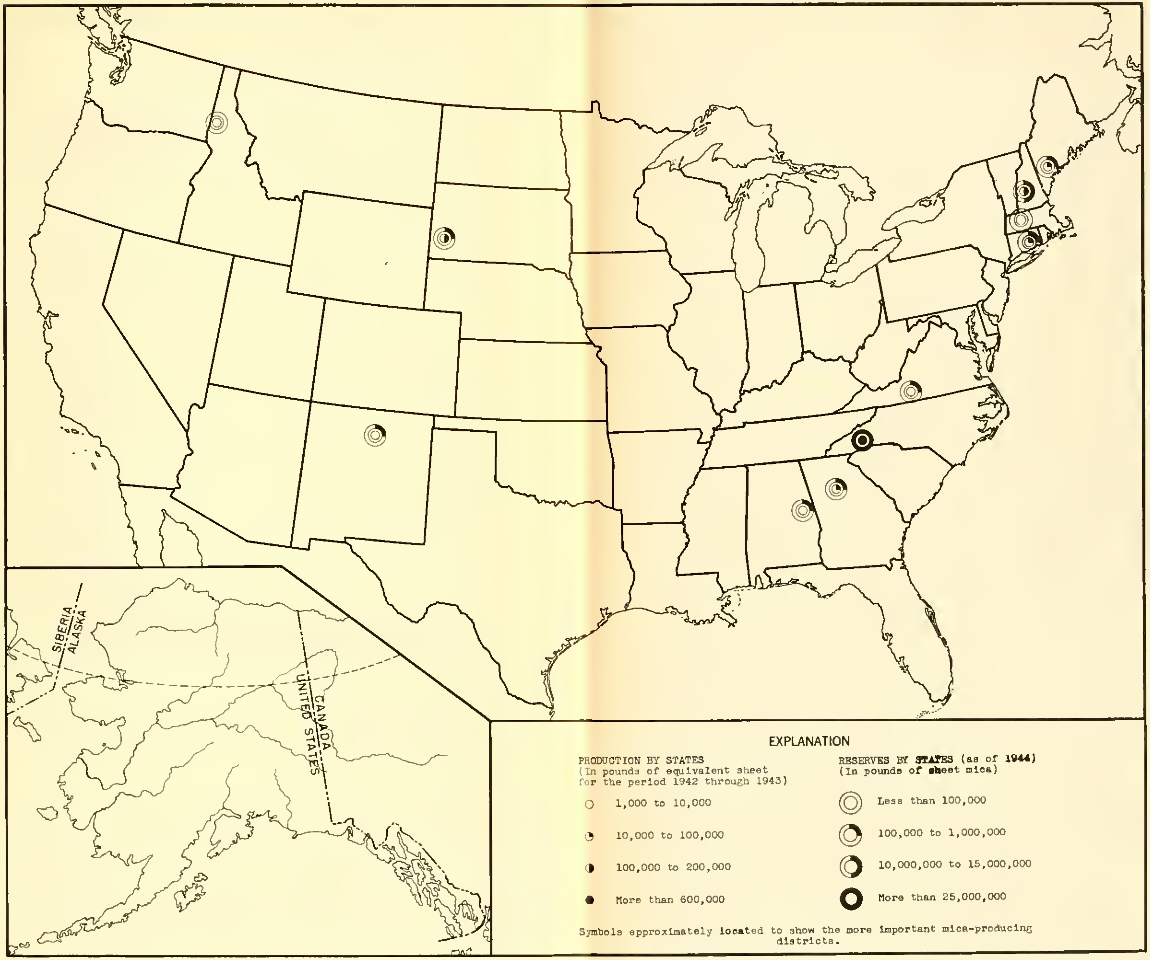

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CHART XVI.—Distribution of sheet-mica production during 1942 and 1943 and estimated reserves in the United States as of January 1944, by States

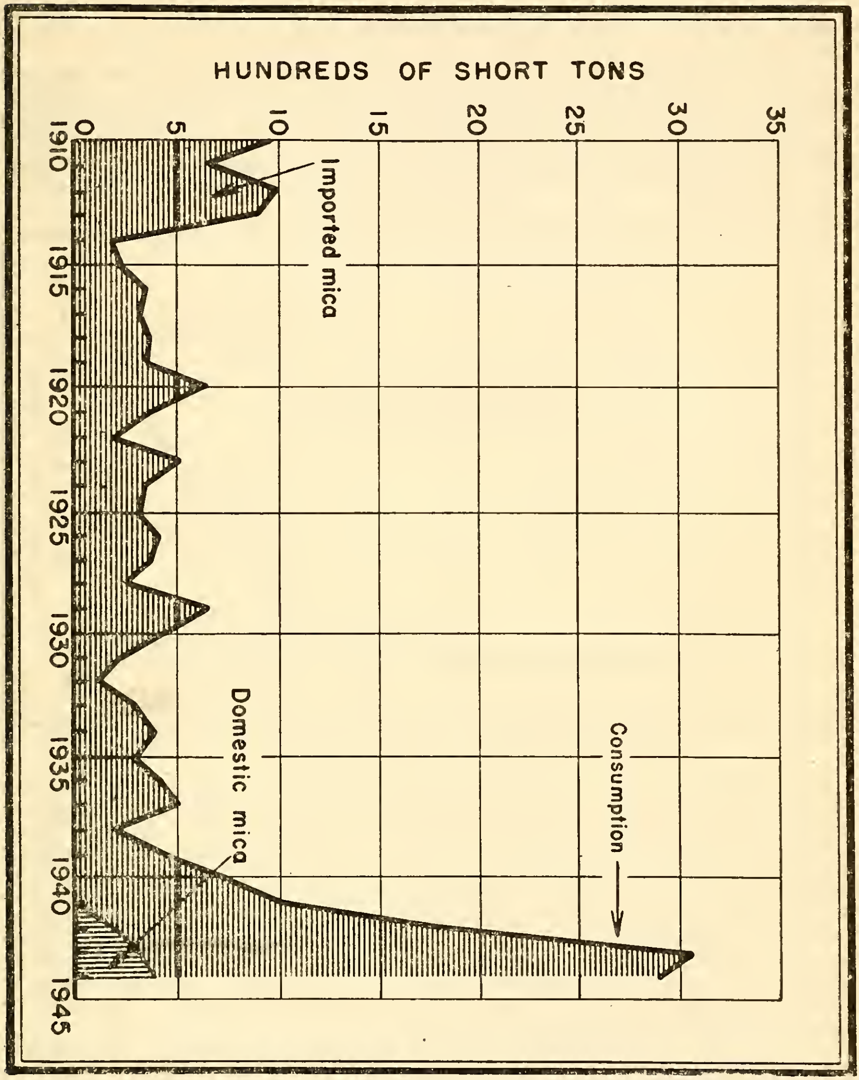

FIGURE 22.—Consumption of strategic mica in the United States, 1910–44.

MOLYBDENUM

By W. S. Burbank,[70] Albin C. Johnson,[71] and C. E. Nighman[71]

More than 95 percent of the molybdenum consumed in the United States is used to impart hardness and toughness to special steels. Molybdenum often is employed in conjunction with, or as a substitute for, chromium, nickel, manganese, tungsten, or vanadium. Minor amounts of molybdenum are used in iron castings, pigments, electrical equipment such as radio and radar, and a variety of special alloys.

Molybdenum and tungsten can be substituted for each other in the function of imparting strength and hardness to steel. At the outset of the present war, molybdenum was substituted for tungsten; later, the supply of molybdenum also became inadequate, and the relative position of the two metals was reversed.

[70] Geological Survey.
[71] Bureau of Mines.

Molybdenum is recovered from scrap steel to some extent by segregating alloy scrap according to composition and remelting it, with small amounts of new alloy metal, to produce steel of the required composition.

Data on domestic consumption have been available only since mid-1941 and for exports only for 1939 and later. During World War II exports were generally less than 25 percent of domestic use and for earlier years have been estimated to range between 50 and 75 percent of domestic consumption. In view of the elasticity of production, domestic output may be said to parallel world consumption. Figure 23 shows actual domestic production and prices, and world production since 1910.

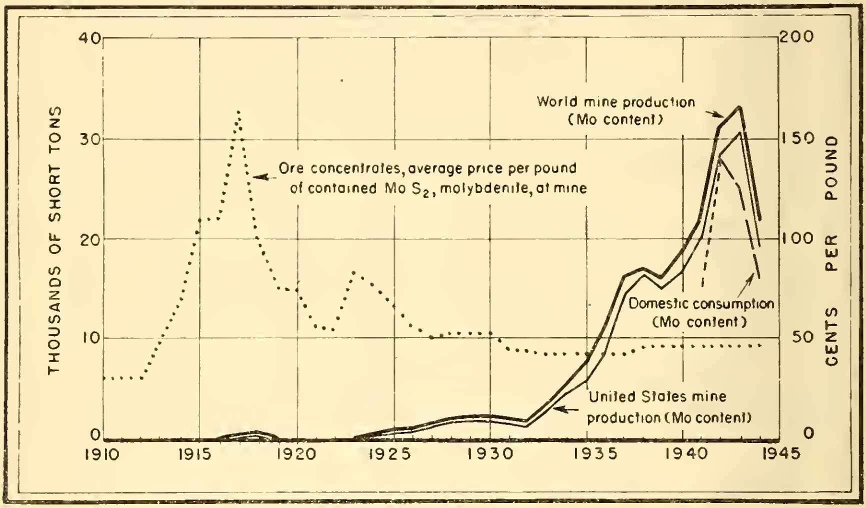

FIGURE 23.—Trends in production and price of molybdenum in the United States and world production, 1910–44.

The principal sources in the United States fall into four categories, only two of which are of appreciable importance. The largest sources are: (1) Those that yield molybdenum alone, represented by the deposits at Climax, Colo., Questa, N. Mex., and Urad (Empire), Colo., and by a number of smaller but not currently commercial deposits; and (2) the byproduct sources from deposits worked for copper. The latter are represented by only four deposits that produced prior to 1944 and have appreciable reserves. One other copper deposit produced molybdenum in 1944 and 1945, and further additions in both of these principal classes may be expected in the future. Miscellaneous byproduct sources include (3) some tungsten deposits and (4) some complex gold-silver base-metal deposits. Few of them contain enough molybdenum to warrant the expense of recovering the metal.

Molybdenum is widespread in some commercial clays and in sedimentary rocks. The content ranges from a few hundredths to about 0.1 percent. The ordinary methods of handling such materials do not permit recovery of the metal, but the newly explored vanadium-bearing phosphatic shales of Idaho, Wyoming, and Montana may prove an exception. Data now available, though still inadequate to permit a sure determination, indicate that the shales carry enough molybdenum in some areas to warrant its recovery as a byproduct should they become commercial sources of vanadium and phosphorus.

Among foreign sources, the copper deposits of Mexico and Chile and the molybdenite deposits of Peru have yielded about 6 percent of the world production in recent years. Molybdenum in the copper deposits of Chile, only part of which is now recovered, constitutes probably the largest known reserve outside of the United States. Known Canadian deposits are unimportant in size. There are deposits in Finland, Norway, Morocco, and Greece, but it seems unlikely that they can meet total European requirements. Deposits in Japan, Korea, Manchuria, South China, and the Soviet Union are not sufficiently well known to permit appraisal of their importance now, but it is likely that those of Manchuria at least will have more than local importance.

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MOLYBDENUM

MINERAL RESOURCES OF THE UNITED STATES

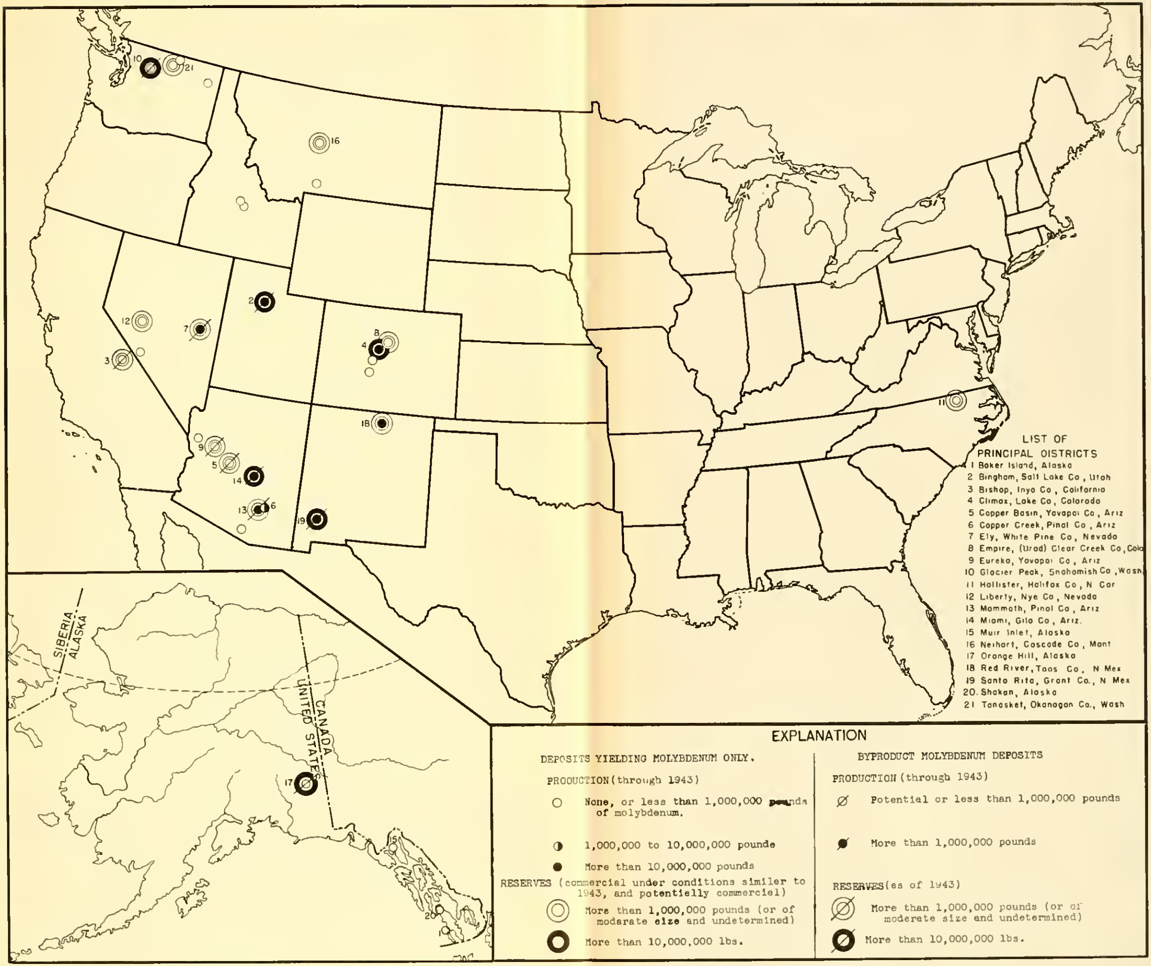

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CHART XVII.—Distribution of production of molybdenum in the United States and Alaska through 1943 and reserves as of 1943, by districts.

Reserves

The molybdenum resources of the United States comprise a larger proportion of known world resources than that of any other metal in common use. Domestic reserves have been segregated into three groups: (1) Deposits valuable principally for molybdenum and those containing molybdenum recoverable as a byproduct under economic and technologic conditions similar to those of 1943; (2) potentially productive deposits that might become available at present or slightly increased prices, or with improvements in technology; and (3) deposits that, because of physical features, grade, or other factors, cannot now be considered commercial and are unlikely to become so in the near future. All of group 1 and an appreciable proportion of group 2 can be considered reserves available now, or in the near future, for normal demands and as supplementary sources in times of national emergency. The accompanying summary, table 26, shows the known measured, indicated, and inferred reserves of molybdenum. Recoverable molybdenum has not been estimated because recovery differs greatly from plant to plant, particularly from byproduct sources where technology is continually improving.

TABLE 26.—*Estimated molybdenum reserves of the United States as of 1943, by commercial availability*

Availability:	*Molybdenum (metal) content (in pounds)*
1. Commercial under conditions similar to those of 1943	2,600,000,000
2. Potentially commercial and marginal	900,000,000
3. Submarginal, more than	3,500,000,000

In group 1 shown in table 26, the grades of ore generally exceed 0.5 percent of molybdenite (molybdenum sulfide, MoS_2), except for the byproduct molybdenum in copper mining, in which the grades range from 0.02 to 0.2 percent of MoS_2. Although the grade of some ores included in group 2 exceeds 0.5 percent of MoS_2, most of the ore is below this grade, but none with a cut-off less than 0.25 percent of MoS_2 is included, except in the byproduct class. In groups 1 and 2 the reserves are considered measured and indicated, except insofar as the byproduct reserves of the larger copper deposits may be classed as inferred.

Chart XVII shows the distribution of molybdenum production and reserves in the United States, by districts.

The reserves in group 3, which are largely inferred, include large deposits in several Western States and Alaska containing 0.05 to 0.25 percent of molybdenite, vanadiferous shales, and partly explored areas adjacent to the principal known molybdenum deposits.

The commercial, potentially commercial, and marginal reserves of molybdenum in the United States are equivalent to over 400 years supply at the average rate of domestic consumption from 1935 to 1939 and nearly 100 years supply at the wartime rate. They are equivalent to the output of about 140 years at the prewar rate of production.

Up to the present the United States has dominated world production and consumption of molybdenum, and its production facilities are flexible enough to meet any anticipated demands. However, in future some competition in world markets may arise, chiefly from South American copper deposits and from recently discovered molybdenum deposits in Manchuria, reportedly of great extent.

NATURAL GAS

By C. H. Dane,[72] H. S. Kennedy,[73] and F. S. Lott [73]

Natural gas has been described as the perfect fuel, as it is of high thermal value, is susceptible to accurate control, and leaves no residue. It also can be processed under a wide variety of conditions to provide raw materials for an almost unlimited number of chemical products. Natural gas can be converted into liquid products for use as motor or other fuels at costs that approach those for similar products from competitive petroleum sources. The liquid hydrocarbons associated with some natural gas are separated from it and marketed as petroleum products; they furnished almost 6 percent of the total domestic supply of petroleum products in 1944.

[73] Bureau of Mines.
[72] Geological Survey.

Natural gas is produced in varying amounts from fields in more than 25 States. Table 27 and chart XVIII show the distribution of natural-gas production and estimated reserves in the United States by regional districts. The location of the gas- and oil-producing fields is also indicated on the chart.

TABLE 27.—*Estimated reserves of natural gas and marketed production in the United States, by districts*

[In billions of cubic feet]

	District 1—New York, Pennsylvania, West Virginia, Ohio, Kentucky, Florida	District 2—Illinois, Indiana, Kansas, Michigan, Missouri, Oklahoma, Nebraska, North Dakota, South Dakota	District 3—Arkansas, Louisiana, Mississippi, New Mexico, Texas, Alabama	District 4—Montana, Colorado, Utah, Wyoming	District 5—California	Total
Estimated proved recoverable reserves Dec. 31, 1945 [1]	4,587.9	23,624.9	106,223.9	2,496.9	10,855.7	147,789.3
Percent of United States reserves	3.1	16.0	71.9	1.7	7.3	100.0
Average annual marketed production, 1943–44 [2]	448.7	482.2	2,074.7	77.4	479.9	3,562.9
Percent of United States production	12.6	13.5	58.2	2.2	13.5	100.0

[1] Estimated by the committee on natural gas reserves, American Gas Association.
[2] Bureau of Mines figures.

Most natural gas is obtained from fields that produce gas only. However, some so-called "wet" natural gas is produced with petroleum and marketed from many oil fields. Some gas is also produced from condensate wells—those in which the liquids obtained at the surface occur as gas in the reservoir and are formed by the decrease in pressure and temperature after the gas leaves the reservoir. Both liquid and gas are recovered at the ground surface. Although condensate fields have been found in California and the Rocky Mountain region, by far the largest number have been found in the Gulf coast area of Lousiana and Texas. Approximately half of the recently discovered fields in the Southwest have been of the condensate type.

During the first 50 years of the natural-gas industry, utilization was confined to areas not more than 100 to 250 miles from the fields, but the discovery of large reserves of marketable gas in dry-gas fields in the Mid-Continent area (notably in Louisiana in 1916 and in the Texas Panhandle in 1918) and the waiting markets for this fuel in urban and industrial centers resulted in the construction, in 1927 and later years, of large-diameter long-distance pipe lines for the transmission of large volumes of gas at high pressure. The total quantity of natural gas marketed in the United States from 1906, the first year of systematic record, through 1944 was 55,313 billion cubic feet (see fig. 24). Rough approximations for earlier years suggest that the total since the birth of the natural gas industry has not been far from 62,000 billion cubic feet.

The average marketed production for 1943 and 1944 is shown in table 27. Over the past 12 years, the trend in volume of marketed production of natural gas has been upward, the average increase having been about 10 percent per year. Continued expansion in the use of natural gas appears to be definitely in prospect. In view of past and current results of drilling, however, probable increases in annual withdrawals will be more than replaced by newly developed supplies for a number of years.

The average value of natural gas at the wells has declined slowly from 11.1 cents per thousand cubic feet in 1922 to a low of 4.5 cents in 1940, reflecting primarily the pressure for a market exerted by the vast gas reserves available in the Southwestern States. In this area, several current trends are evident whose influence is toward a firmer field price and improvement in conservation practices. They include progressive opening of larger markets for gas, increased return of produced gas to oil and condensate reservoirs, greater utilization of liquefied gases, and growing effectiveness of State regulatory laws and their administra-

NATURAL GAS

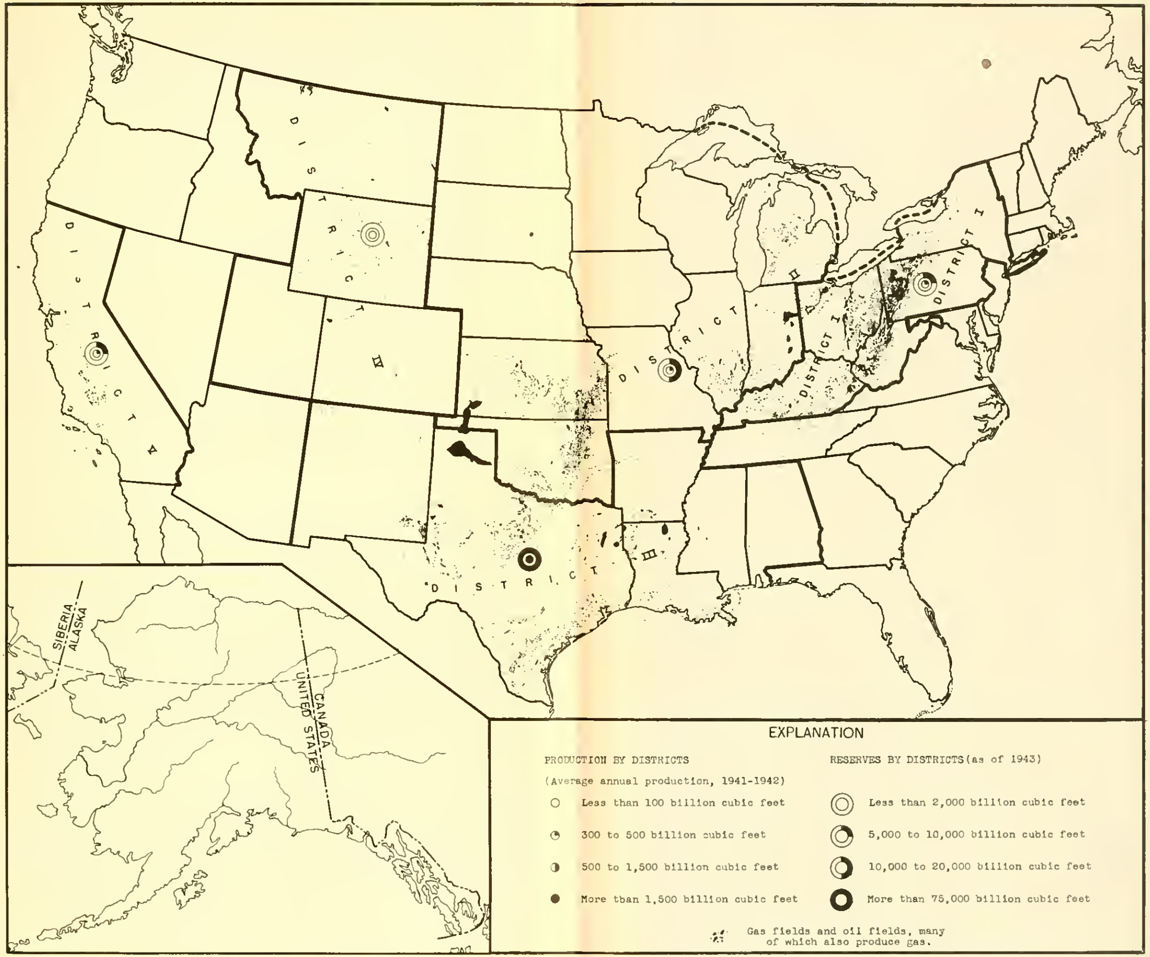

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CHART XVIII.—Distribution of production and reserves of natural gas in the United States, by districts.

tion. Under prevailing practice, relatively less gas is wasted incident to the production of oil than formerly, as the gas in excess of that required for field use is delivered to pipe lines if a market is available. So far as is known at present, very little gas is wasted from dry-gas fields.

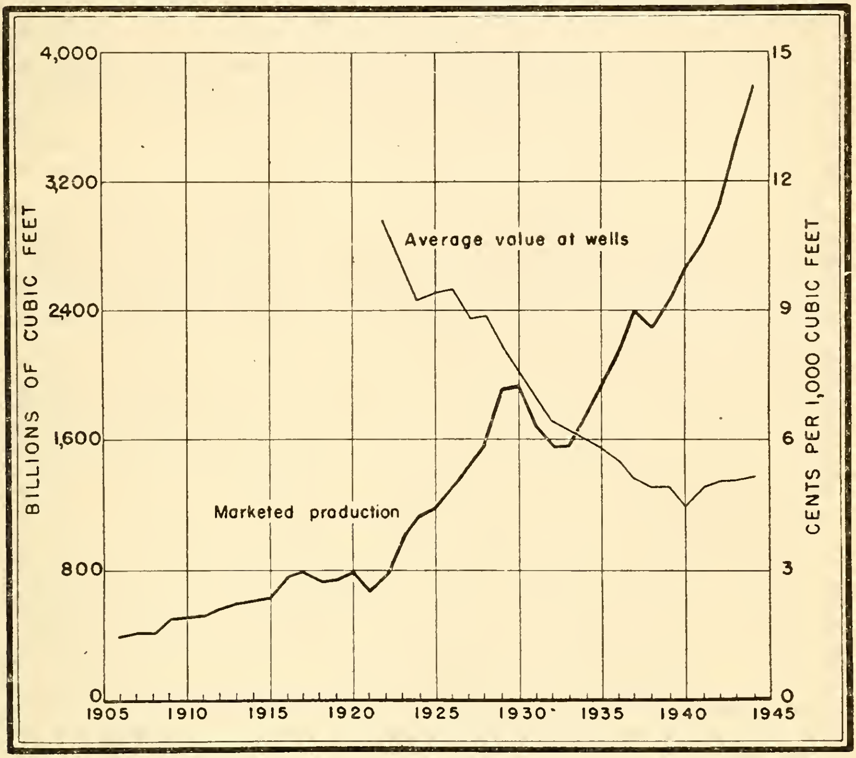

FIGURE 24.—Trends in production and price of natural gas in the United States, 1904–44.

Reserves

The estimates of natural-gas reserves in table 27 are taken from the first report of the committee on natural-gas reserves of the American Gas Association. They include only proved, recoverable reserves determined by comprehensive studies of field conditions carried on by qualified industry subcommittees, each assigned to one of seven districts into which the country was divided for convenient group operation. The five districts indicated in table 27 and chart XVIII provide a regional basis for appraising sources of supply of natural gas.

The reserves are divided into three types, according to modes of occurrence, as follows:

1. Nonassociated gas (free gas not in contact with crude oil in the reservoir)—111 trillion cubic feet.
2. Associated gas (free gas in immediate contact with crude oil in the reservoir)—20 trillion cubic feet.
3. Dissolved gas (gas in solution in crude oil in the reservoir)—17 trillion cubic feet.

It thus appears that the gas contained in dry-gas and condensate reservoirs, included in item 1, represents the dominant source of supply—75 percent of total reserves.

The committee's report gives reserves by States, calculated at a pressure base of 14.65 pounds per square inch, absolute, and at a standard temperature of

60° F.[74] As stated therein: "The recovery factors and abandonment conditions assumed in the individual fields differ as widely as the characteristic circumstances in each field."

The committee expects to investigate natural-gas reserves as of the end of each year to provide for the future a continuing index of the supply position of the industry.

The estimate of proved, recoverable reserves, indicating for the United States as a whole about 148 trillion cubic feet of gas, may doubtless be regarded as conservative. In the words of E. L. DeGolyer, with reference to a similar estimate in 1946: "The estimate is conservative, as are all estimates which must be proved by the information available. We are still of the opinion * * * that for broad considerations of national planning, we would be well advised to consider our gas reserves to be of the order of magnitude of 200 trillion cubic feet."

As an indication of the relationship between the anticipated supply and the rate of depletion to serve current markets, the average rate of withdrawal in 1943–44 amounted to 2.4 percent per year of the estimated reserve. Rates of gas production from dry-gas reservoirs are adaptable to varying market conditions over a relatively wide range during much of the life of the fields. However, as the fields approach exhaustion, declining rates of withdrawal from them are inevitable. A long-sustained or increased production rate can be achieved only by developing additional sources of supply.

The ultimate reserves of gas available under future economic and technologic conditions include the gas that will be available for marketing from oil fields. In the more recently discovered fields most of the gas is available except an amount equal to a few percent of production, which is used for field fuel and other purposes. The gas reserves in condensate fields will be available to pipe lines after completion of the process by which liquids are recovered, and the gas remaining is pumped back into an underground reservoir.

Large quantities of gas in dry-gas fields, associated with petroleum, or as recoverable fractions in condensate reservoirs, remain underground as yet undiscovered. However, no quantitative estimate of these additional discoveries can be made previous to development. Most of the present reserve of gas has been found as a result of exploratory drilling for petroleum, and drilling experience has shown that the chances of discovering gas are better than of discovering petroleum. In addition, within the past few years a general trend is apparent toward the discovery, at greater depth, of higher proportionate quantities of gas and condensate. Therefore, prospective discoveries of gas per unit volume of oil discovered may increase, particularly in the western part of the Mid-Continent and Gulf coast regions and in California.

Table 27 shows that the supply of gas in relation to marketed production varies widely in several districts shown. In district 1, with declining productivity of wells and increased requirements, transmission facilities have been overloaded in periods of peak demand. New supplies drawn from the surplus reserves of the Texas Gulf coast were made available to the Appalachian region in the winter of 1944–45, when a long-distance pipe line from the Texas Gulf coast to West Virginia was completed for this purpose, with the approval of Government regulatory agencies.

In district 5 (California), local shortages developed during the war in certain areas where a heavy concentration of war industries caused sharp increases in demand. Difficulties in adapting transmission facilities to the new conditions have been aggravated by decreased availability of oil-field gas in some connected fields and by the lack of additional supplies at points convenient to the major markets in the southern part of California. Natural gas from oil fields in that State has been the major source of suppy for the State's pipe lines, but in future the dry-gas and condensate reservoirs promise to have primary importance. A major pipe line has been proposed to bring gas from Texas fields to markets in southern California.

The gas reserves in district 4 are relatively small and geographically remote from large population centers; hence demands upon them have been moderate and chiefly of local character. Their sufficiency for present markets is indicated by the prospective supply of over 32 times recent annual rates of withdrawals,

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[74] McGowan, N. C., American Gas Association committee report, gas, November 1946, p. 33.

the probability of additions through discovery, and utilization of oil-field gas for fuel where and when an economic incentive is present.

Further expansion of the natural-gas industry appears to depend upon the tremendous reserves in district 2 (Illinois, Indiana, Kansas, Michigan, Missouri, and Oklahoma) and in district 3 (Arkansas, Louisiana, Mississippi, New Mexico, and Texas), which together are credited with 87.9 percent of the national total. Nine major pipe-line systems are now moving gas from these districts to the North, East, and West, and a tenth is under construction. The indicated abundance of this premium fuel is eloquently confirmed by a market value at the wells of about 3 cents per thousand cubic feet in many producing fields.

Nickel

By W. S. Burbank,[75] H. W. Davis, [76] and Albin C. Johnson,[76]

Nickel is used chiefly as an alloying element in various types of nickel steel. It is also used in alloys with copper, brass, and bronze, for plating metals, as an active chemical constituent of storage batteries ,and as a catalyst.

Where suitable and available, molybdenum, chromium, and vanadium, as alloying elements, and carbon steel in place of nickel steel, are substituted for nickel.

From 1863 to about 1893 the Gap mine near Lancaster, Pa., was the source of the Nation's supply of nickel, but since it was abandoned the United States has depended upon foreign sources of nickel, and this situation may be expected to continue indefinitely. The Sudbury district of Canada has yielded most of the world requirements—80 to 85 percent in recent years—and probably will continue to do so for many years because it contains the world's largest known reserve of nickel. New Caledonia has in the past yielded 10 percent of the world's production; but its proportion has fallen to 5 percent in recent years, and this downward course may be expected to continue. Production from Cuban ores was begun in 1943 and by 1945 had surpassed the production of New Caledonia. The ores developed in Cuba, although containing only 0.8 to 1.5 percent of nickel, constitute a large reserve, and if development can be extended economically throughout areas underlain by similar deposits, the available reserves will be increased enormously. Based upon general assumptions as to their distribution and thickness, these Cuban laterite deposits amount to an estimated 3 billion tons containing 0.8 to 1 percent of nickel and 1 to 2 percent of chrome. As a result of the process developed at the Nicaro plant, the Cuban deposits may supplement other sources of domestic supply in the post-war period. Substantial reserves of nickel ore are found in Brazil, the Celebes, Philippine Islands, and Burma, but their relative unavailability and the lack of facilities for operating them will probably prevent these areas becoming more than minor sources of our supply for some years. The Soviet Union, by acquiring the Petsamo deposit in Finland, probably will be an important factor in future nickel production.

In the United States the byproduct output of a few hundred tons of nickel each year from the refining of copper ores was supplemented during the World War II by production from domestic ore of the Fredericktown area, Mo., in which nickel and cobalt occur in association with lead and copper. The other nickel deposits of the continental United States and Alaska that are known to have large tonnages were either too low grade or of such mineralogical nature that they could not be exploited, even under the emergency war conditions.

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[75] Geological Survey.
[76] Bureau of Mines.

Figure 25 shows the relation between production, consumption, world output, and foreign trade in nickel. The average quoted price of electrolytic nickel has ranged from 45 to 30 cents per pound during the period 1910 to 1928, but since 1929 it has been 35 cents.

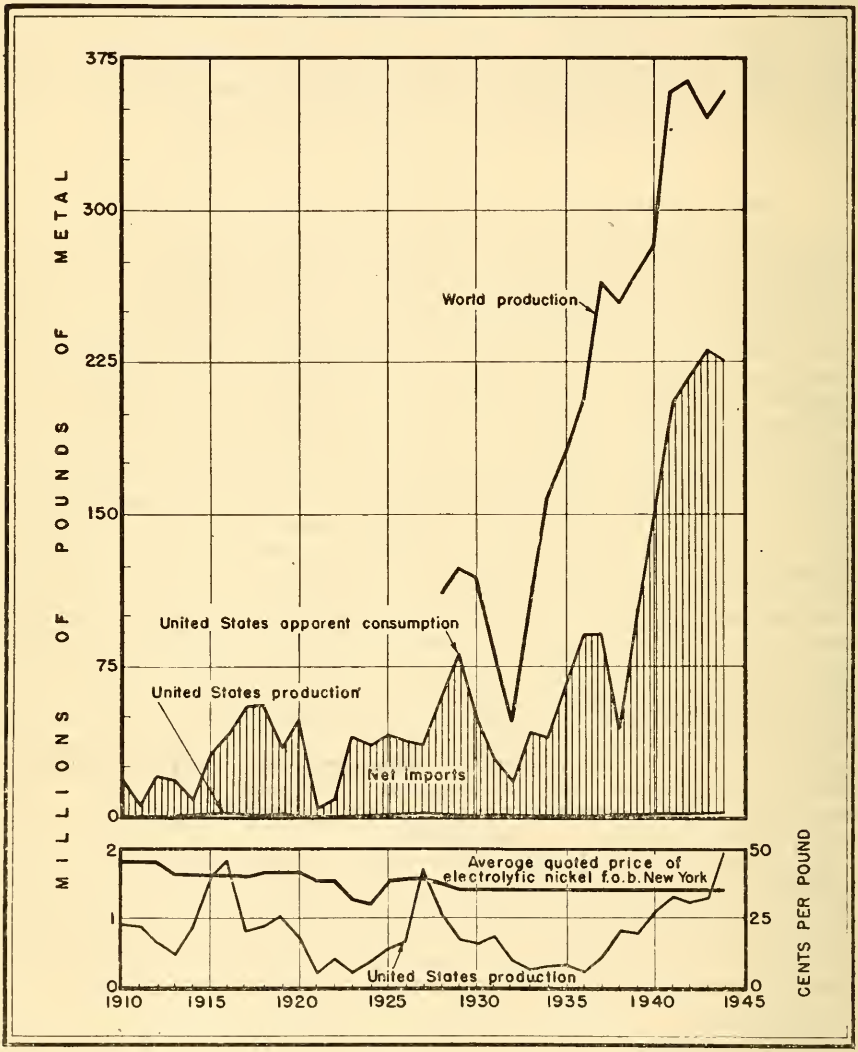

FIGURE 25.—Trends in production, consumption, and price of nickel in the United States and in world production, 1910–44.

Reserves

There are three general types of nickel ores: (1) Sulfide ore, (2) nickel silicate ores low in iron, and (3) low-grade nickel ferous iron ores. The known indicated and inferred nickel deposits of the continental United States and Alaska are largely noncommercial under normal conditions. The reserves are summarized in the accompanying table 28. Measured ore is included with indicated ore because the nature of the information at hand does not permit stating it separately.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY AND BUREAU OF MINES

NICKEL

MINERAL RESOURCES OF THE UNITED STATES

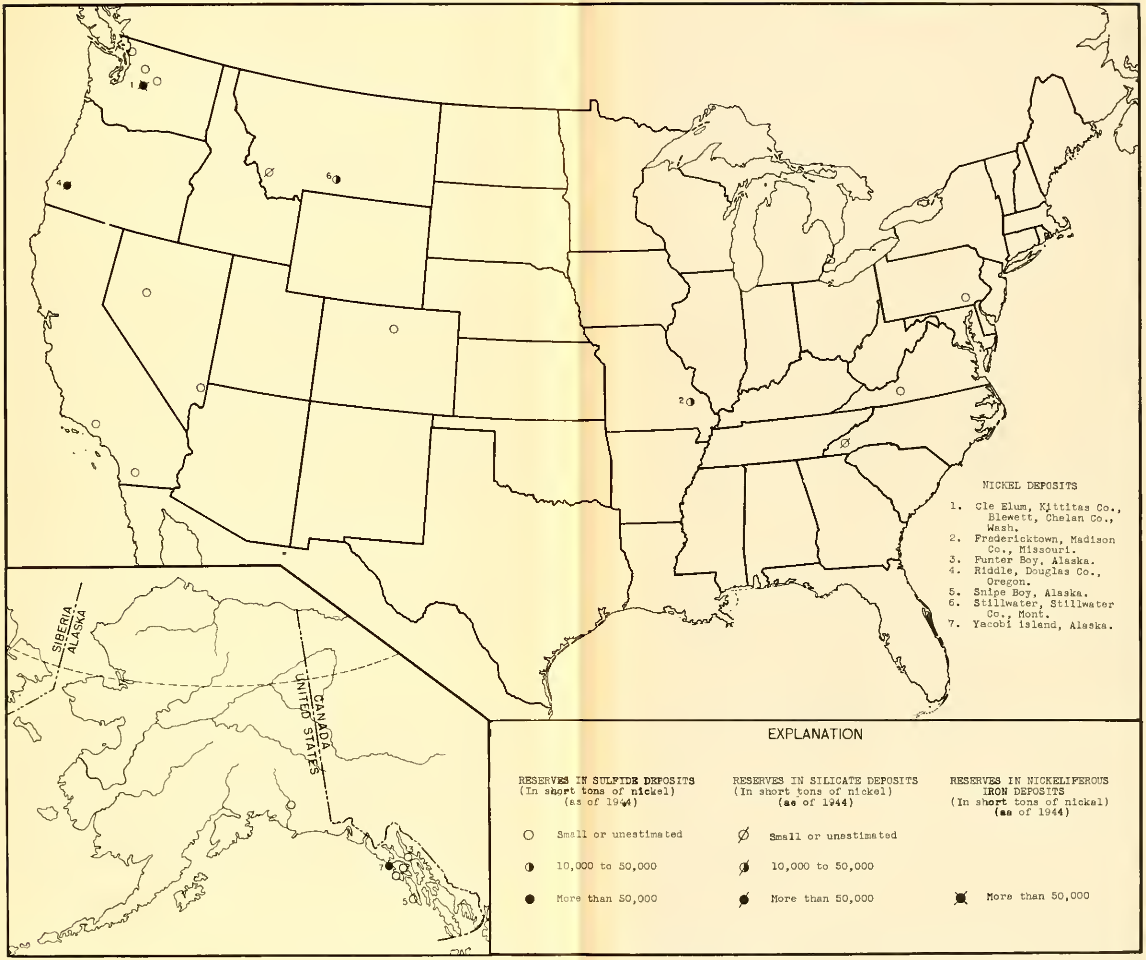

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Chart XIX.—Distribution of known nickel resources in the United States and Alaska as of January 1944.

TABLE 28.—*Estimated nickel reserves in the United States as of January 1944*

[In short tons]

	Indicated [1]		Inferred		Total [2]	
	Ore	Nickel [2] content	Ore	Nickel [2] content	Ore	Nickel content
Sulfide ores:						
Alaska	11,000,000	40,000	11,000,000	30,000	22,000,000	70,000
States	6,500,000	35,000	7,500,000	35,000	14,000,000	70,000
Silicate and nickeliferrous iron ores: States	15–20,000,000	175,000	25–30,000,000	235,000	40–45,000,000	410,000
Total [2]	35,000,000	250,000	45,000,000	300,000	80,000,000	550,000

[1] Includes measured ore.
[2] Round numbers.

The higher-grade sulfide ores, except those at Fredericktown, Mo., are found in small bodies in widely separated parts of the country. Most of them are small and expensive to explore; and they are too few to warrant establishment of a smelting industry. The larger bodies contain scarcely more than a few hundred tons of nickel in ore whose average grade is 1 to 3 percent. The potentially more important sulfide deposits are those at Yakobi Island, Alaska, and at Mouat, Mont., in which the larger and better-grade bodies have an averge nickel content of about 0.4 percent. Many of the deposits contain various amounts of copper, platinum, and cobalt, which enhance their value slightly.

The better-grade silicate ores, as represented particularly by the deposits at Riddle, Oreg., contain 1 to 2 percent of nickel and are low in iron. Although the potential tonnage of the nickeliferous iron ores of Washington containing nickel is large, the grade is low—about 0.5 percent of nickel or less—and commercial methods of treatment have not been developed. Chart XIX shows the distribution of the nickel resources of the United States and Alaska as of January 1944.

Utilization of each of the various types of ore involves special problems, and the relative grades do not represent the relative worth of the ore. The Bureau of Mines has experimented with the silicate and iron ores and believes that virtually all the nickel can be recoved in a nickel-iron alloy.

With incentive for development and further exploration for these known types of deposits, it may be expected that considerably larger reserves than have been indicated in the above table will be revealed. Not less than 10 times the currently estimated reserves is reasonably expectable from present knowledge of the distribution of deposits and the thoroughness with which they have been explored. In Alaska, particularly, only a few of the geologically favorable areas have been prospected for nickel. Some bodies known to contain nickel have not been sampled systematically.

NITRATES

By Eugene Callaghan,[77] B. L. Johnson,[78] and W. H. Waggaman [78]

The atmosphere is an inexhaustible source of nitrogen, but it was not until World War I that processes for its extraction and use (the fixation of nitrogen) were developed on a commercial basis. Ammonia recovered as a byproduct in the coking of coal is another important source of nitrogen and represents nearly 20 percent of the total domestic production. The principal mineral source of nitrogen is the caliche of northern Chile—a mixture of sodium nitrate, potassium nitrate, sodium sulfate, and sodium chloride, from which the sodium nitrate of commerce is produced. This is the source of most of our imports of nitrate. The fertilizer and explosive industries absorb the bulk of both the manufactured and the natural nitrate, but a small quantity is used in the manufacture of a variety of chemical products.

[77] Geological Survey.
[78] Bureau of Mines.

The economic trends of the domestic nitrate industry are shown in figure 26. The annual net consumption between 1936 and 1939 ranged between 541,400 and 625,800 short tons of contained nitrogen. Imports for 6 years (1938–43) averaged 130,000 tons per year of contained nitrogen or 757,675 short tons of material. The enormous demands of the explosives industry during the recent

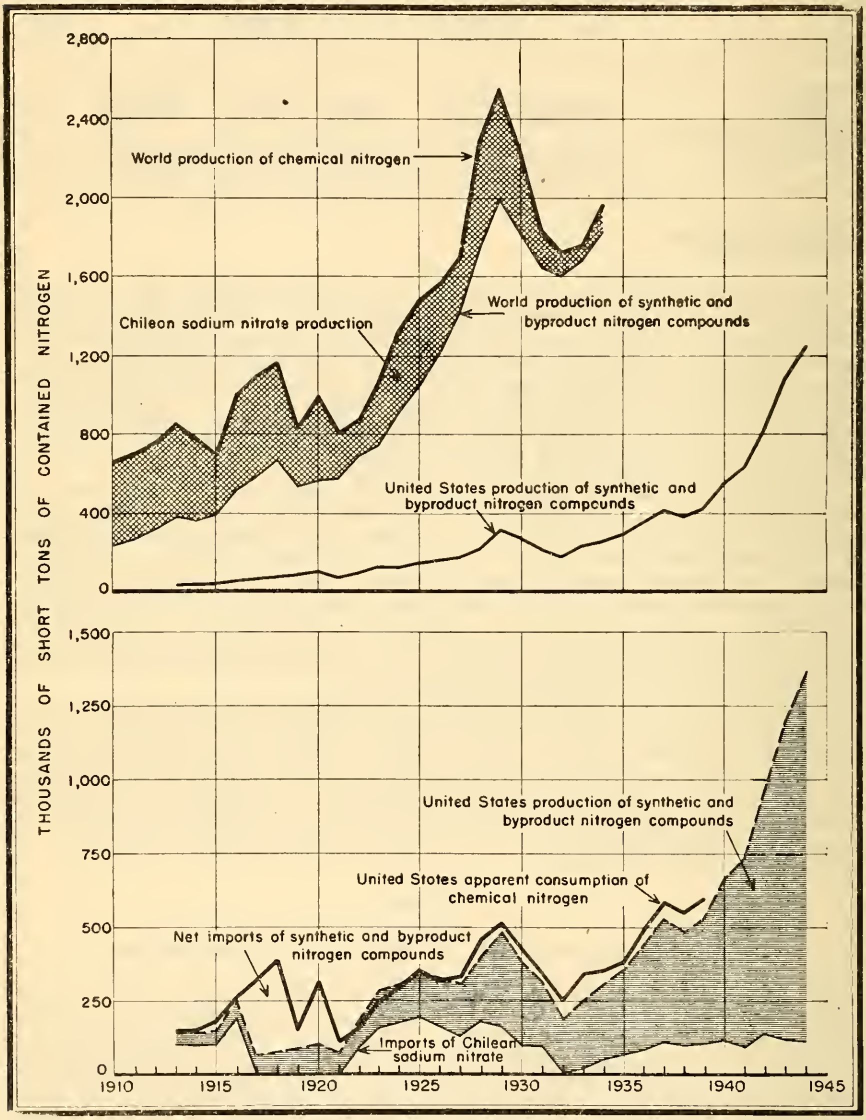

FIGURE 26.—Trends in production, consumption, and imports of chemical nitrogen in the United States and in world production, 1910–44.

war, as well as increased demands from agriculture, have brought about a great increase in domestic plant capacity which has proved ample for present needs. Synthetic nitrogen plants now can produce 1,137,900 tons of fixed nitrogen, and byproduct plants can yield 227,700 tons—a total of 1,365,600 short tons annually.

Domestic sources of natural nitrates are small, scattered, and of no commercial importance so far as competition with fixed atmospheric nitrogen and imported Chilean nitrate is concerned. The only deposit of any consequence—in southwestern California—is estimated to contain 1,900 short tons of nitrate. Playa deposits in the arid Southwest and cave deposits derived from animal droppings contain small amounts. In contrast, the deposits of Chile contain reserves of many millions of tons.

Petroleum

By H. C. Fowler,[79] H. D. Miser,[80] and A. C. White[79]

To meet the future petroleum needs of the country adequately in the face of increasing demands and the natural decline in production capacity is a challenge to science and technology. How long the rate of discovery of new oil can pace current withdrawals is not known. The experience of the past 5 years indicates that it is becoming increasingly difficult and costly to find new reserves. Therefore, exploration and development must be pursued more vigorously and encouraged at a price commensurate with the increased cost of and need for new sources of supply if the desired goal is to be attained. However, the country will not face the period of acute declining petroleum supply from wells, whenever that may be, without preparation. "Substitute" or alternative fuels and other products from oil shale, oil-saturated sands, coal, and natural-gas synthesis are only on the threshold of their development and utilization.

PRODUCTION

The cumulative output of crude petroleum in the United States through 1944 has totaled about 30,000,000,000 barrels. Before World War II the United States was producing about 61 percent of the total world output of crude petroleum, but this proportion rose to 68 percent in 1943.

The production of crude petroleum in the United States reached an all-time record of 1,678,000,000 barrels in 1944 and was supplemented by the record production of 100,000,000 barrels of natural gasoline and other condensable hydrocarbons. An examination of production rates, by States, from 1939–44 indicates important changes in the source of crude supply. (See table 29.) These changes are primarily related to reserves but have been strongly influenced by temporary problems in war transportation. Even with a 33-percent gain in crude-oil production from 1939 to 1944, drastic restrictions in less-essential civilian consumption were necessary during this period to supply the military demands for petroleum.

DEMAND

A primary problem in future oil supply arises from the rapid expansion in demand and the trenmendous quantities required. The average annual consumption of all oils, in continental United States and its Territories, rose from about 1,068,000,000 barrels in the 5-year period 1934–38 to an average of 1,414,000,000 barrels annually in the period 1939–43—a gain of 32 percent. During most of this time, the domestic supply of crude petroleum has been abundant. The average value of crude oil at the well from 1934 to 1943 ranged from $0.97 to about $1.21 a barrel. The abundance of crude oil has resulted in large volumes of fuel oils competing with coal.

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[79] Bureau of Mines.
[80] Geological Survey.

TABLE 29.—*Production of crude petroleum in the United States, 1859–1944, by States*

[In millions of barrels]

State	1939	1940	1941	1942	1943	1944	Cumulative production, 1859–1944
Arkansas	21.2	25.8	26.3	26.6	27.6	29.4	616.4
California	224.4	223.9	230.2	248.3	284.2	311.8	6,644.7
Colorado	1.4	1.6	2.2	2.2	2.3	3.1	49.7
Illinois	94.9	147.6	132.4	106.4	82.3	77.4	1,098.1
Indiana	1.7	5.0	7.4	6.7	5.3	5.1	155.6
Kansas	60.7	66.1	83.2	97.6	106.2	98.8	1,506.8
Kentucky	5.6	5.2	4.8	4.5	7.9	9.6	193.9
Louisiana	93.6	103.6	115.9	115.8	123.6	129.6	1,544.9
Michigan	23.5	19.7	16.4	21.8	20.8	18.5	222.5
Mississippi	.1	4.4	15.3	28.8	18.8	16.3	83.8
Montana	6.0	6.7	7.5	8.1	7.9	8.7	115.7
Nebraska	----------	.3	1.9	1.2	.6	.4	4.4
New Mexico	37.6	39.1	39.6	31.6	38.9	39.6	424.4
New York	5.1	5.0	5.2	5.4	5.1	4.7	139.1
Ohio	3.2	3.2	3.5	3.5	3.3	2.9	601.7
Oklahoma	159.9	156.2	154.7	140.7	123.1	124.6	5,349.3
Pennsylvania	17.4	17.4	16.7	17.8	15.8	14.1	1,061.5
Texas	483.5	493.2	505.6	483.1	594.3	746.7	8,909.5
West Virginia	3.6	3.4	3.4	3.6	3.3	3.1	424.2
Wyoming	21.5	25.7	29.9	32.8	34.2	33.4	631.2
Other States	.1	.1	.1	.1	.1	.1	1.4
Total	1,265.0	1,353.2	1,402.2	1,386.6	1,505.6	1,677.9	29,778.8

Source: Bureau of Mines.

The United States has been a net exporter of petroleum and its products for many years. Crude petroleum and fuel oils predominate in the imports, while gasoline and lubricants are important exports, together with substantial quantities of crude petroleum destined to Canada. In balancing imports into the continental United States and noncontiguous Territories against exports to foreign countries, there was an average annual net export of about 87,000,000 barrels (7 percent of the total demand) during the 5-year period 1934–38 and of about 60,000,000 barrels (4 percent of the total) for the 5-year period 1939–43. The primary sources of oil imports have been Mexico and Venezuela. Most of the imports have entered Atlantic coast ports and have been particularly important as a source of heavy fuel oil and asphalt. Production and reserves have expanded steadily in the Caribbean area and would furnish an important supplementary supply if domestic production should prove inadequate. From the standpoint of present known reserves, the most important source of increased future world supply appears to be the Persian Gulf area. The extent to which future supplies for the United States may be drawn from this area will be determined by political controls, transportation facilities and cost, and competition from other potential consumers.

Figure 27 shows the trends in world production and in production, demand, and average prices of petroleum in the United States from 1914 to 1944.

About 97 percent of the crude oil consumed in the United States is converted into finished products at refineries and chemical industry plants. The larger part of the natural gasoline is blended with components obtained from crude oil at refineries. Therefore, any analysis of total oil demand requires consideration of the demands for the various individual products. The domestic demand for the principal petroleum products for a normal year (1940) is given in the Bureau of Mines Minerals Yearbook as follows:

Product	Domestic demand (millions of barrels)	Percent of total
Motor fuel	589.5	44.4
Kerosine	68.8	5.2
Distillate fuel oil	160.8	12.1
Residual fuel oil	340.2	25.6
Lubricating oil	24.7	1.9
Miscellaneous	142.6	10.8
Total domestic demand	1,326.6	100.0

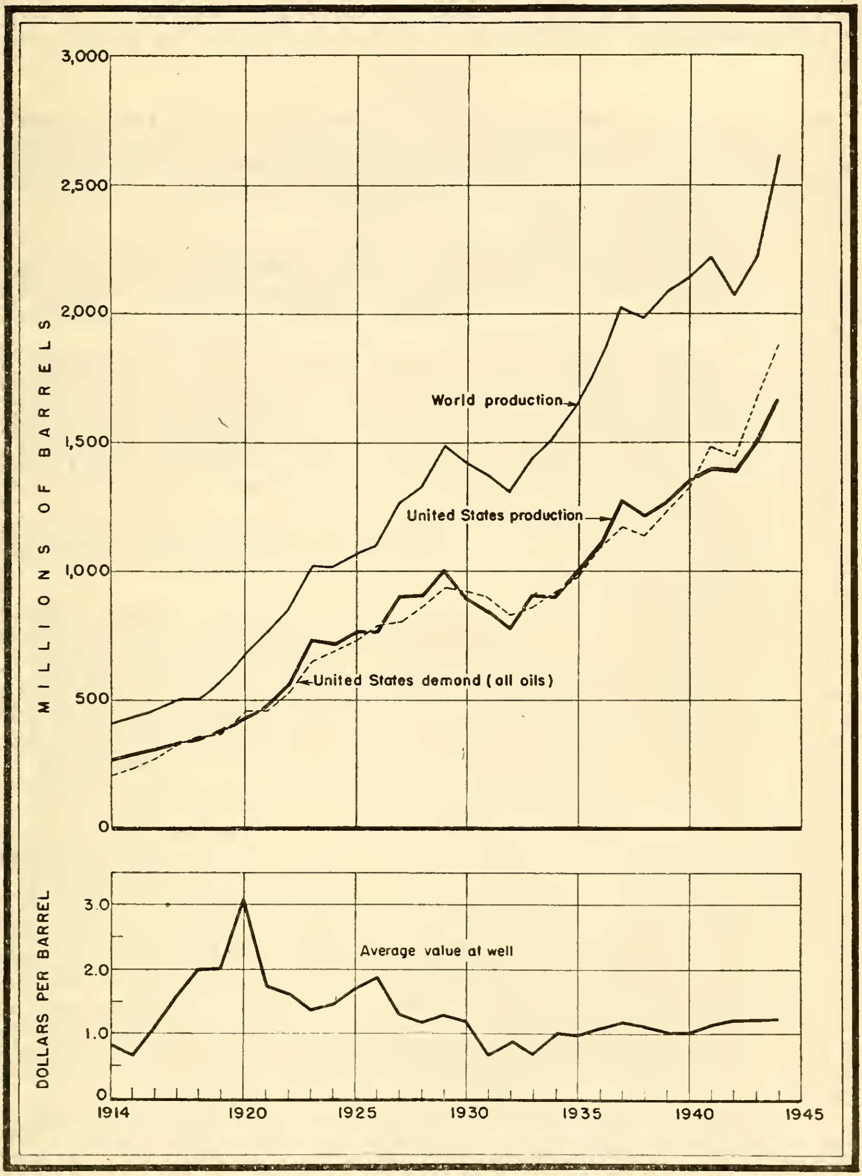

FIGURE 27.—Trends in production, demand, and price of crude petroleum in the United States and in world production, 1914–44.

The major advance in refining technology has been to secure greater flexibility in the volume production of the products most desired, and the relative yields of various products can now be varied almost at will. Thus, a major part of the 500,000,000 barrels of distillate and residual fuel oils consumed in the United States in 1940 could have been converted into motor fuel, and twice the quantity of lubricating oil could have been made.

Failure to develop large, new oil reserves, either in this country or abroad, and a substantial increase in price would result in a sharp decline in the total demand for fuel oils. Under those conditions an adequate supply of motor fuel might be maintained by more economical engine design, by increased yields from

the available crude oil with a corresponding decline in the manufacture of fuel oils, or by manufacture at higher cost from other sources, such as oil shales or coal.

OCCURRENCE

Since 1859, when the first commercial oil well was drilled in the United States, the search for petroleum has been extended not only into many States but also to greater depths. In recent years Mississippi, Nebraska, Virginia, Alabama, and Florida have been added to the list of States that produce oil, bringing the total to 26. Also, Alaska contributed some petroleum—126,579 barrels from the Katalla field from 1902 to 1933.

As a result of deeper drilling in recent years, the proportion of the country's petroleum reserves at depths below 5,000 feet has increased rapidly, and a substantial part of the known extractable oil occurs at depths between 5,000 to 10,000 feet. A relatively small part of the known reserves lies between 10,000 and 13,503 feet.

In recent years, condensate-type reservoirs have become an important source of petroleum products. Although fields of this general type are widely distributed. a large majority are found in the coastal areas of Texas and Louisiana. Perhaps more than 100 of these fields are known, but the actual potentialities of many are not yet determined. Known condensate reserves have been estimated to represent about 5 percent of the total liquid petroleum reserves in the United States, and 44 percent of all discoveries in the Southwest during the first half of 1943 are stated to be condensate fields.

The oil-bearing rocks are widely distributed in the 26 producing States and are of many different ages. They occur in all parts of the geological column from the Ordovician to the Pliocene. In Alaska the petroleum-bearing rocks are of Mesozoic and early Tertiary ages.

Anticlines have been sought for many years as favorable structural features on which to drill for oil, but the drilling to date and current knowledge of the occurrence of petroleum have shown that oil accumulation is associated with many other types of structural features, including faults, salt domes, and buried hills. Moreover, it has been found that many petroleum reservoirs belong to a type commonly known as stratigraphic traps and from them one-fourth to one-third of the domestic production to date has been obtained. Because past development has tested an increasing number of favorable structural traps and has thereby reduced the number remaining to be discovered, the search for stratigraphic traps has been intensified in recent years.

Large geologic provinces in the United States contain sedimentary rocks and structural features that are favorable for the formation and accumulation of petroleum in commercial quantities. (See chart XX.) In only relatively small areas, aggregating about 6,000,000 acres, in these provinces, has oil been discovered and produced. Further development of their petroleum resources is invited by offshore areas along the California coast and the Gulf coast of Louisiana and Texas and numerous unexplored inland areas in many States and Alaska. Large areas in the States now producing and in nonproducing States are not favorable for finding commercial quantities of oil. Although continued improvements in drilling technique have made it possible to drill wells in search of oil to greater and greater depths, there is a limit below which oil will not be found. In many areas this limit is clearly marked by the floor or basement of crystalline rocks.

In others, the oil-bearing rocks may be less clearly limited in their lower extension by sedimentary rocks whose consolidation or other features, such as low porosity and permeability, preclude their containing natural petroleum reservoirs.

RESERVES [81]

The proved reserves of petroleum in the United States at the end of 1943 were estimated by the American Petroleum Institute to be 20,064,150,000 barrels, by the Oil and Gas Journal to be 20,046,905,000 barrels, and by the Oil Weekly to be 19,755,253,000 barrels. (See table 30.) According to these estimates, a little more than half of the proved reserves are in Texas. No data on the petroleum reserves of Alaska are available.

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[81] After this summary was prepared the American Petroleum Institute estimated proved petroleum reserves at 20,827,000,000 barrels as of the end of 1945, indicating that additions to proved reserves have more than equaled the depletion in 1944 and 1945.

PETROLEUM

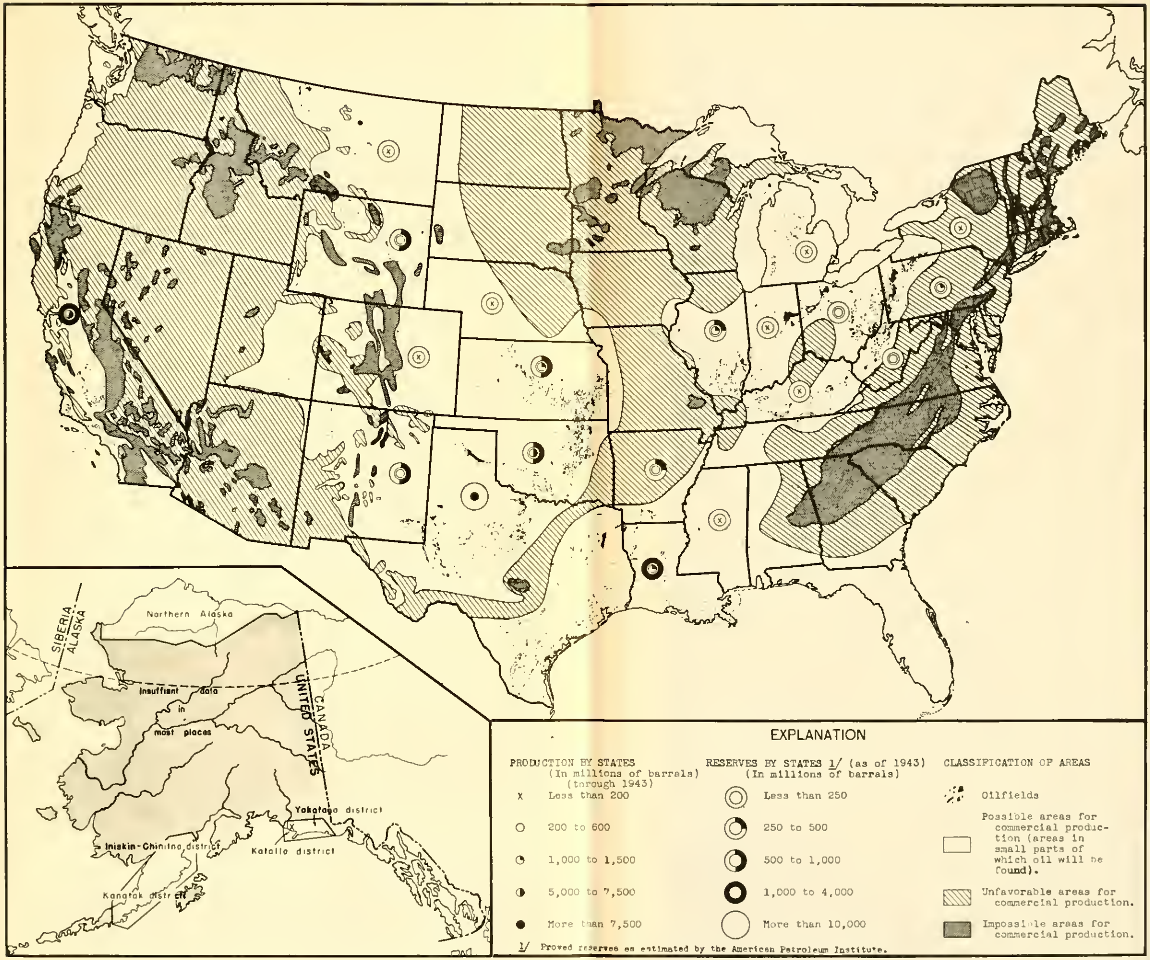

CHART XX.—Distribution of past production and reserves of petroleum in the United States and Alaska as of 1943, by States, and classification of areas as to oil-production potentialities.

The American Petroleum Institute estimate refers solely to proved or blocked-out reserves of crude oil (including condensate) known to be recoverable under existing economic and operating conditions and therefore includes no estimate of:

1. Oil under the unproved portions of partly developed fields.
2. Oil in untested prospects.
3. Oil that may be present in unknown prospects in regions believed to be generally favorable.
4. Cashinghead gasoline extracted at natural-gasoline plants in moderately low-pressure fields.
5. Oil that may become available by secondary-recovery methods from fields where such methods have not been applied.
6. Oil that may become available through chemical processing of natural gas.
7. Oil that can be synthetically recovered from oil shale, coal, or other substitutes.

TABLE 30.—*Estimated proved reserves of petroleum in the United States at end of 1943, by States*

[In thousands of barrels of 42 gallons]

State	American Petroleum Institute [1]	Oil and Gas Journal [2]	Oil Weekly [3]
Arkansas	296, 929	367, 301	318, 956
California	3, 336, 823	2, 980, 082	2, 989, 191
Colorado	45, 111	[4] 30, 779	43, 096
Illinois	294, 622	415, 135	292, 211
Indiana	31, 039	31, 696	30, 274
Kansas	645, 952	905, 145	658, 215
Kentucky	35, 190	[5] 45, 905	31, 848
Louisiana	1, 483, 826	1, 073, 412	1, 439, 467
Michigan	55, 248	94, 768	58, 280
Mississippi	38, 872	48, 213	26, 908
Montana	108, 057	103, 317	84, 801
Nebraska	1, 000	[6] 1, 941	1, 508
New Mexico	653, 981	582, 049	661, 164
New York	90, 525	45, 724	49, 394
Ohio	32, 643	33, 203	31, 744
Oklahoma	908, 618	1, 109, 181	935, 047
Pennsylvania	137, 323	181, 522	137, 477
Texas	11, 324, 954	11, 346, 019	11, 475, 143
West Virginia	43, 839	33, 970	43, 849
Wyoming	499, 394	617, 543	445, 959
Miscellaneous	[7] 306		[7] 221
Total	20, 064, 152	20, 046, 905	19, 755, 253

[1] American Petroleum Institute, Report of Committee on Petroleum Reserves, Feb. 19, 1944.
[2] Oil and Gas Journal, vol. 42, Jan. 27, 1944, pp. 116–117.
[3] Oil Weekly, vol. 112, Jan. 31, 1944, pp. 78–83.
[4] Includes Utah.
[5] Includes Tennessee.
[6] Includes Missouri.
[7] Includes Florida, Missouri, Tennessee, Utah, and Virginia.

In considering the moot question of reserves, it must be realized that no estimate of "recoverable oil" can be precise or static. Even when correction factors are applied continually, estimates for a single field may differ widely from year to year. In the over-all annual estimates for the country, individual differences tend to equalize one another. Therefore, despite the many physical, economic, and other factors involved, it seems reasonable to accept the current estimates of about 20,000,000,000 barrels of crude petroleum, including condensates, recognizing that this figure should be corrected periodically as the numerous variables are evaluated more accurately.

SUBSTITUTES

A principal substitute source of products heretofore obtained from petroleum is oil shale. According to Winchester's estimate of 92,000,000,000 barrels of oil recoverable from oil shale in the United States, this substitute source is nearly twice as large as the sum of all the petroleum that has been produced in the United States since 1859 and the quantity in known reserves. Surface and near-surface deposits of oil-saturated sand and shales—especially in the

Western States—hold large quantities of petroleum products for future extraction; likewise, liquid hydrocarbons in large volume can be obtained by processing natural gas which otherwise might be wasted. The situation with respect to bituminous coal and lignite, of which there are reserves of about 3.2 trillion tons in the United States, has been summarized by A. C. Fieldner as follows:

"* * * Most of our bituminous coal and lignite can be liquefied by the Bergius pressure-hydrogenation process, and all ranks and grades of coal can be converted to liquid fuel by way of water gas, as developed by Fischer and Tropsch. Both processes are in commercial use in Germany, where more than half of the supply of gasoline is thought to be made from bituminous and brown coal. Costs by these methods are estimated to be three or four times that of producing gasoline from petroleum in the United States."

The position, extent, and quantity of reserves represented by the Nation's resources of oil shale, oil-saturated sands, and coal are determinable with reasonable accuracy before actual development. Assuming that an adequate price prevails, they can be used according to market demand. This contrasts with the utilization of petroleum and natural gas, which in the past have alternately pressed for market or been scarce without regard to actual demand. Another difference is that the cost of producing petroleum increases as a field is drained, whereas the cost of producing petroleum products from shale, oil-soaked sands, and coal should be relatively constant. Their possibilities are being explored assiduously by both Government and industry. Some of this work is supported by the Synthetic Liquid Fuels Act (Public Law 290, approved April 5, 1944).

FUTURE SUPPLY

The proved reserves of petroleum in the ground are constantly changing in quantity. They are depleted by the output of producing wells and increased by the discovery of new fields and deeper pools. The maintenance of reserves with adequate productive capacity to meet the demand for petroleum requires the continuous discovery and development of a volume of new reserves equal to, or larger than, the current demand. The extent to which new supplies of oil are made available depends not alone upon the unpredictable volume yet to be discovered but also upon the solution of increasingly difficult problems of discovery, development, refining operations, and percentage yields of products. In part, it depends upon the payment by consumers of prices for petroleum products that will permit the industry to carry the heavy and increasing costs of finding and developing needed new oil reserves. Although a substantial yield comes from the different fields whose peak of production has passed (in 1942 the output from these fields totaled more than 203,000,000 barrels from about 293,000 so-called stripper wells), 85 percent of the petroleum output is derived from relatively young fields in the flush stages of production. In each year from 1937 to 1943, the number of oil wells completed and their initial daily production have declined, although this trend was revised in 1944. The present trend in availability of petroleum is of national concern.

Much oil in new fields remains to be discovered and in deeper strata of known fields; but the number of new fields yet to be found, whatever they may be, is definitely limited, and each newly found field leaves one less to be discovered.

The petroleum resources discovered and developed in the United States total about 50 billion barrels, comprising 30 billion barrels produced through 1944 and 20 billion barrels of proved reserves. The magnitude of the "unproved reserves" cannot be estimated. In fact, oil in the ground is not a "reserve" until it has been found and its extraction assured. Moreover, some of the oil in a reservoir can never be extracted, even by the most effective methods, although the percentages brought to the surface of the ground have been increasing as a result of continually improved operating procedures.

The expression of petroleum reserves in terms of years' supply gives no true measure of their magnitude or the length of time required for their extraction. Invariably when such an arithmetical manipulation is used, confusion of thought and action results. It is of prime importance, in times like the present, especially, to know more about the rates of availability of the crude oil and its associated natural gas. No field can produce at a higher rate than this for long without loss in ultimate production. The normal decline of productive capacity of wells and fields varies widely, depending on many factors, but after the "flush" production stage, a substantial part of the oil now in proved reserves cannot be "recovered" for 20 or 30 years or even longer. Therefore, it is assured that some oil will be produced, although at diminishing rates, from fields now known for many years.

Phosphate Rock

By Eugene Callaghan,[82] B. L. Johnson,[83] and W. H. Waggaman [83]

The United States has almost unlimited supplies of phosphate rock, and American agriculture is assured of a continuous supply of this fertilizing material for many hundreds of years. Deposits in Florida and Tennessee, close to the markets and to ocean transportation, are exploited in a large way. Minor quantities, not now exploited, occur in South Carolina, Arkansas, and Kentucky. The larger resources of the Western States—Idaho, Wyoming, Montana, and Utah—are much farther from large markets and yield only a small proportion of current production. Imports are almost negligible, but exports normally amount to nearly one-third of the total United States production.

The economic trends in the phosphate-rock industry are shown in figure 28. A pertinent fact to be noted is that the annual domestic production for the 10-year

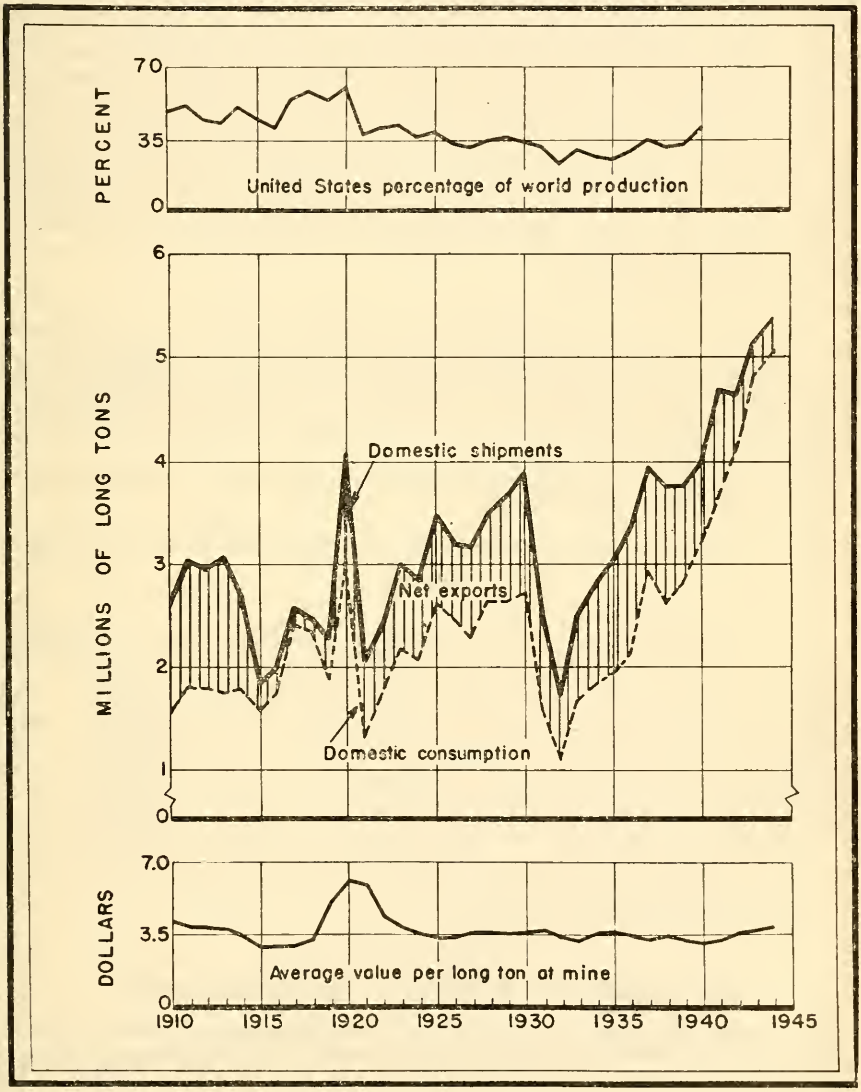

Figure 28.—Trends in production (shipments), consumption, and price of phosphate rock in the United States, 1910–44.

[82] Geological Survey.
[83] Bureau of Mines.

period, 1933–42, is 3,779,910 long tons, whereas the production for 1943, stimulated by war demands and increased buying power of farmers, amounted to 5,126,232 tons. By comparison, for the period 1938–40, the average annual foreign production was 7,225,000 tons. The average annual net consumption in the United States for 1933–42 was 2,826,987 tons. Sales depend not so much on fluctuations of price as upon the buying power of the farmer, foreign demand, and available shipping.

The deposits in Florida and Tennessee extend as blankets over large areas at or near the surface. Those in Florida in part contain pebbles or rock fragments rich in phosphate in a matrix of clay and sand and in part are surface accumulations derived from the weathering and erosion of the original deposits. In Tennessee the deposits now being mined are entirely products of weathering.

In the western field, the deposits are phosphatic shales and phosphate rock. Much of the formation is deeply buried. The average grade of material that is mined in these deposits contains 70 percent of B. P. L., or "bone phosphate of lime" (tricalcium phosphate). "Bone phosphate of lime" is an arbitrary designation of grade obtained by multiplying the P_2O_5 (phosphorus pentoxide) content of the rock by 2.184. Although the entire formation (the Phosphoria formation), whose thickness is as much as 230 feet at the Conda mine in Idaho, is phosphatic, only a few beds 2 to 8 feet thick contain as much as 70 percent of B. P. L.

The favorable competitive position of the Florida deposits—due to relative richness of ores, cheap mining costs, good transportation, and proximity to markets—means that Florida will maintain its leadership for many years. Much of the western phosphate is far from railroads and in high, relatively inaccessible country, but with an increase in the use of fertilizers west of the Mississippi River and solving some of the difficulties of transportation and higher cost of mining incident to the nature of the deposits, the western phosphate can assume great commercial importance.

Reserves

Table 31 lists the estimated reserves of phosphate rock in the United States. Of the grand total of 13,000,000,000 long tons, somewhat over 2,000,000,000 tons is considered available under present technologic and economic conditions. To the approximately 11,000,000,000 tons remaining could be added further large tonnages of phosphate in phosphatic limestone in Florida and Tennessee and in the phosphatic shales of the West not now included in any enumeration because their extent has not yet been appraised.

Chart XXI shows the total production of phosphate rock in 1943 and the estimated reserves as of 1943, by States.

TABLE 31.—*Reserves of phosphate rock in the United States as of 1943, by States*

[In long tons]

State	Measured	Indicated	Inferred	B. P. L., percent
Florida	2, 058, 583, 000	1, 227, 150, 000	1, 796, 000, 000	55–74
Idaho [1]			5, 736, 000, 000	70+
Utah [1]			1, 741, 000, 000	40+–70
Montana [1]			391, 000, 000	70+
Wyoming [1]			116, 000, 000	70+
Tennessee	93, 800, 000			35+
Arkansas [1]			20, 000, 000	
South Carolina [1]			9, 000, 000	
Kentucky [1]			1, 000, 000	
Total	2, 152, 383, 000	1, 227, 150, 000	9, 810, 000, 000	

[1] Measured and indicated included in inferred.

PLATINUM METALS

By H. W. Davis,[84] J. B. Mertie, Jr.,[85] and McHenry Mosier [84]

The platinum metals consist of platinum, palladium, iridium, osmium, rhodium, and ruthenium. They are utilized as pure metals, as platinum-group alloys, as alloys with other metals, as clad metals, and as pure or alloyed platings. The

[84] Bureau of Mines.
[85] Geological Survey.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY AND BUREAU OF MINES

PHOSPHATE ROCK

MINERAL RESOURCES OF THE UNITED STATES

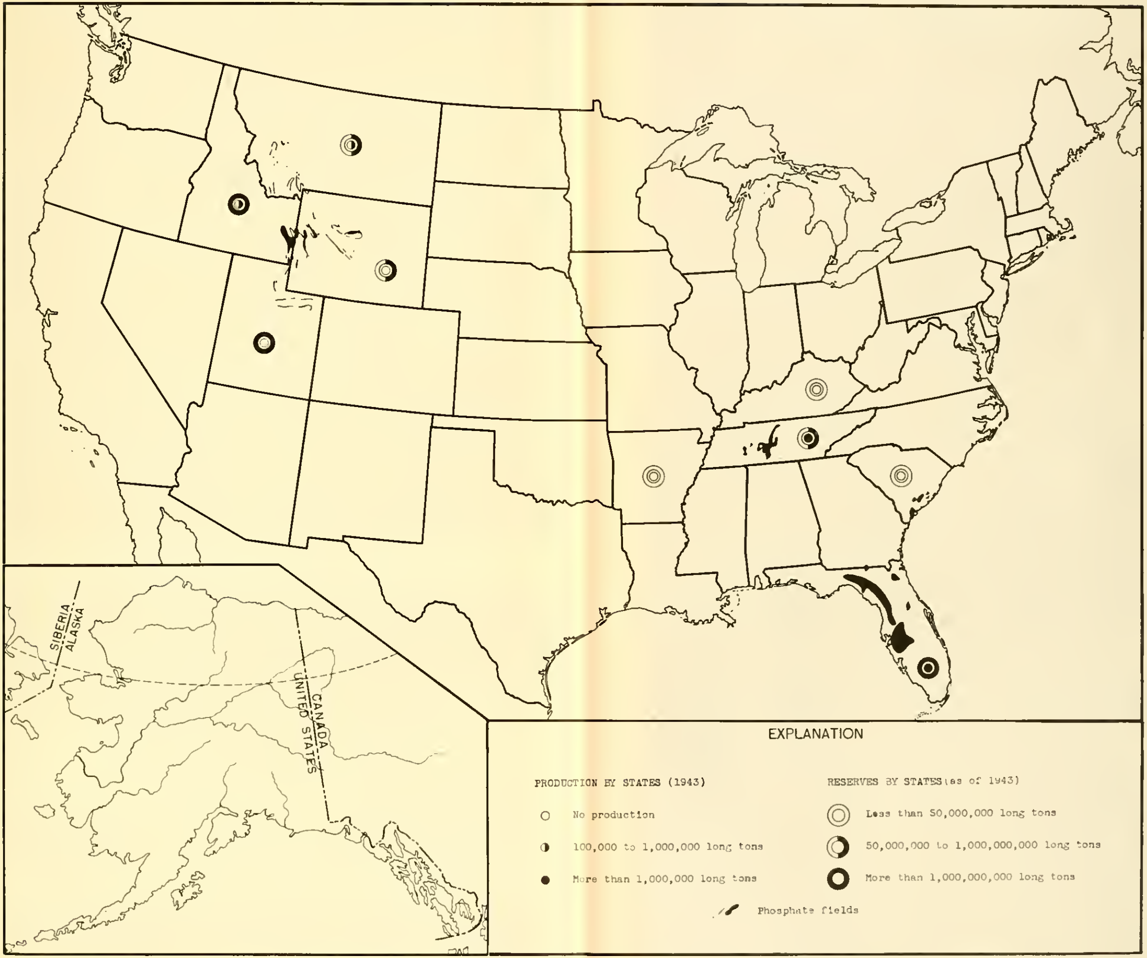

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CHART XXI.—Distribution, by States, of phosphate-rock production in 1943 and estimated reserves in the United States as of 1943.

principal applications are in jewelry, dentistry, and in the chemical and electrical industries; but smaller amounts are needed for numerous other purposes. Platinum, the most widely used of these metals, comprised 61 percent of the total sold to consumers in 1944. Palladium, the next in importance, constituted 34 percent. Substitutes for the platinum-group metals have proved satisfactory for particular uses, but no general substitute has been found.

The world's supply of platinum metals comes from both placers and lodes. The Soviet Union is now the largest producer of placer platinum, followed by Colombia and the United States. Canada is the largest producer of platinum from other sources, followed by the Union of South Africa.

The sources of the platinum metals have changed progressively during the twentieth century. Up to 1920, almost all of the world production came from placers; but the increasing production (principally from the Sudbury district of Canada and from the Union of South Africa) soon altered this situation, and from 1935 to 1944, the placers have produced 23 to 43 percent, with an average of 33 percent. From 1900 to 1914, Russia produced about 95 percent of the platinum metals and Colombia most of the remainder; but from 1915 to 1924, Russia and later the Soviet Union supplied about half of the world output and Colombia about a third, while Canada and the United States furnished the remainder. Since 1934, Canada has been the world's largest producer, the Soviet Union second, and the Union of South Africa third. Up to 1937, the output from Colombia exceeded that of the United States; but since 1938, the United States has ranked fourth and Colombia fifth in world production.

The platinum placers of the Goodnews Bay district of southwestern Alaska were discovered in 1926, and dredging of these deposits was begun in 1937. From 1938 to 1944, they have contributed about three-quarters of the production of the United States. Next in domestic importance are the platinum metals recovered as byproducts of the mining of gold and copper lodes, mainly in the western United States. A small production originates as a byproduct of gold placer mining, principally in California; and a very small amount of platinum metals has been recovered from one platinum lode. Since 1938 the output of the United States has constituted 4 to 9 percent of the world output.

Figure 29 shows the production and consumption of platinum metals in the United States, the relation of domestic to world production, and the prices of platinum from 1920 to 1944. Little consistent relationship is discernible between the production, consumption, and quoted prices of platinum, probably because the platinum metals recovered as a byproduct of nickel mining in Canada constitutes a large part of the present production and this output can be controlled to fit the demands of the market.

Reserves

The reserves of platinum metals in the United States are shown in table 32. The reserves available in the platinum placers of Alaska and in the platinum bearing gold placers of the Western States have been estimated by conventional methods and have been grouped as a single item. The quantity of platinum metals recoverable from gold and copper lodes has been calculated by taking percentages of the gold and copper reserves as indicated by past experience. No attempt has been made to anticipate future changes in methods of recovery or in prices; therefore, the totals given represent the reserves that are available with the technology and market conditions that prevailed in 1944.

TABLE 32.—*Estimated reserves of recoverable platinum metals in the United States, including Alaska, as of January 1944*

[In troy ounces]

Source	Measured and indicated	Inferred	Total
Placers (platinum and gold)	160,000	155,000	315,000
Gold and copper lodes	149,000	135,000	284,000
Platinum lode	1,000		1,000
Total	310,000	290,000	600,000

The output of placer platinum in Alaska is limited at present to the production of a single dredge, and the output of the platinum metals recoverable from the gold and copper ores of the western United States is limited by the

rate of exploitation of such ores. The reserves shown in table 32 are equivalent to about 2½ years supply at the 1940 rate of consumption; but, for the reasons stated above, these platinum metals can be recovered only over a long period of years.

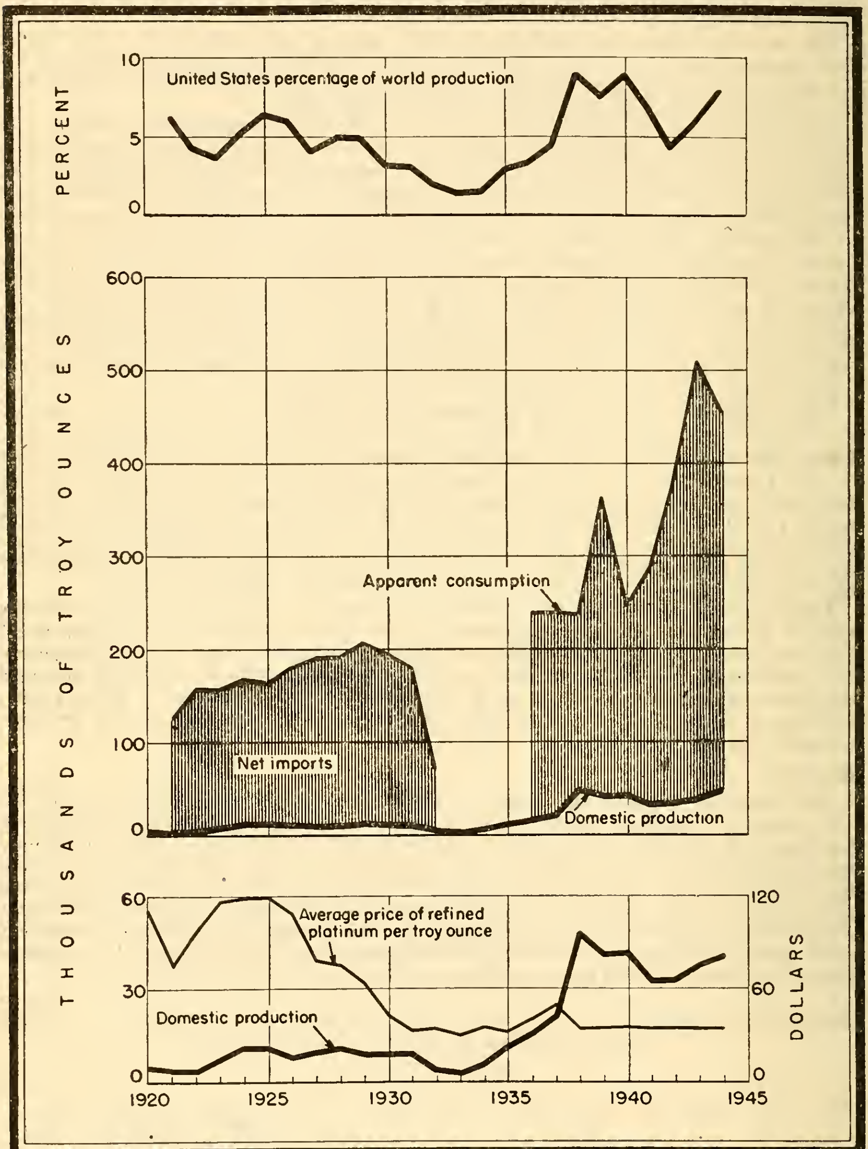

FIGURE 29.—Trends in platinum-metals industry in the United States, 1920–44. Foreign trade data not available from 1932–36.

POTASH

By Eugene Callaghan,[86] B. L. Johnson,[87] and W. H. Waggman [87]

Potash is a prime necessity in agriculture, and most of the production is used in the fertilizer industry. Only a comparatively minor amount (about

[86] Geological Survey.
[87] Bureau of Mines.

10 percent) is taken by the various chemical industries. Although normally the United States has imported considerable potash, during World War II the domestic industry was able to meet most national requirements at no marked increase in price—in great contrast to conditions during World War I, when there was an acute shortage and prices fluctuated wildly.

About 80 percent of the domestic output comes from three mines in southeastern New Mexico, which are mining sylvite (potassium chloride) and a small amount of langbeinite (a sulfate of potassium and magnesium) in salt deposits of Permian age. The sylvite and langbeinite are freed of associated salt and minor quantities of other minerals and distributed to the fertilizer and chemical industries. Most of the remainder comes from saline lake brines in California and Utah. All other sources, including wood ashes, kelp, and byproducts from molasses and cement plants, supply only 0.5 to 1 percent of the total production.

The accompanying graph (figure 30) shows the growth of the American potash industry and its relation to other economic trends. The average annual pro-

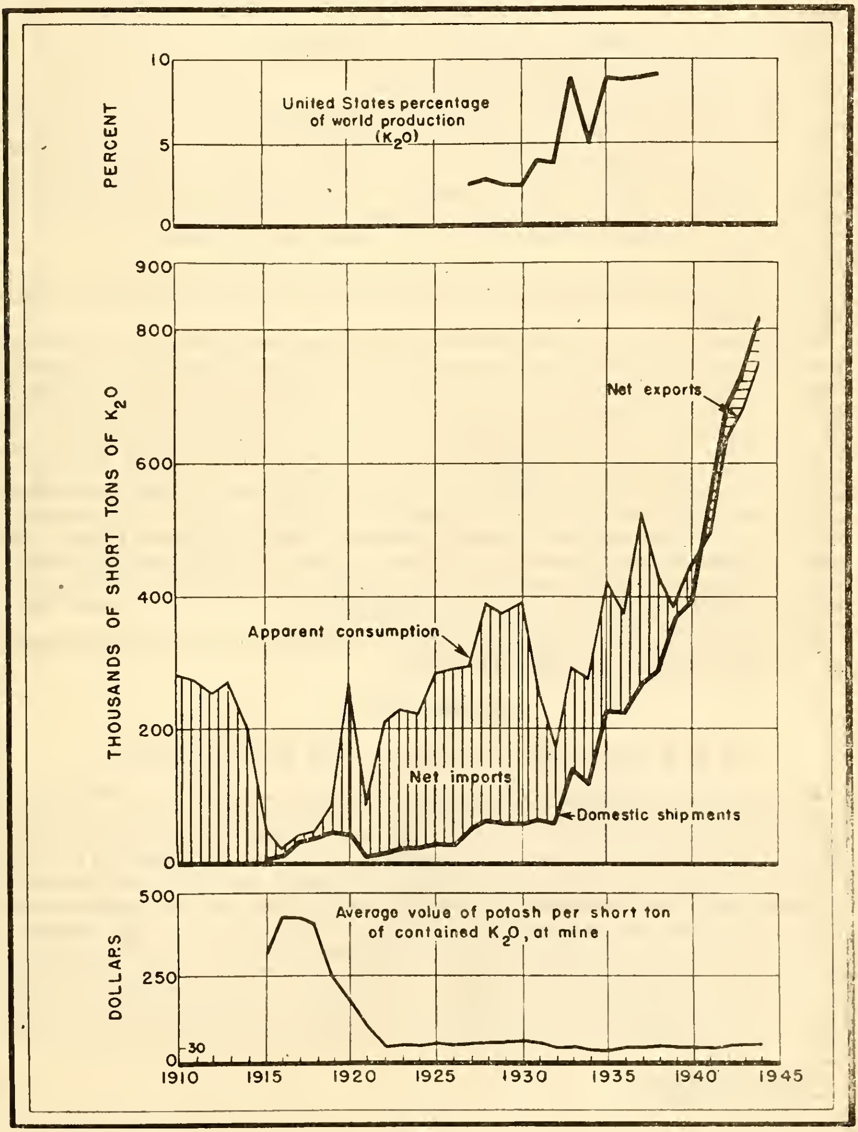

Figure 30.—Trends in production (shipments), consumption, and price of potash in the United States, 1910–44.

duction for the 10-year period 1933–42 was 322,526 short tons of potash (K_2O). In 1943 wartime demands and increased capacity for production brought the domestic yield to 739,141 tons of K_2O. The annual net consumption for the 10-year period 1933–42 was 430,497 short tons of K_2O. Consumption has varied greatly, depending on the buying power of the farmer. When World War II began, the price of 60-percent potassium chloride (muriate) was maintained at 53½ cents per 20-pound unit of K_2O. Potassium sulfate costs about 75 cents per unit of K_2O.

Before the workable deposits of sylvite in New Mexico were discovered and developed in 1930, Germany was the main source of potash used in this country. When imports were cut off during the First World War, a host of potash-bearing materials, including alunite, greensand, leucite rock, and various saline lake and playa deposits, were investigated, and some were mined. However, the potash from most of these materials could be obtained only at high cost, so that, with the resumption of imports, production from these sources ceased.

Reserves

The brine in the mush of salt crystals at Searles Lake, Calif., is estimated to contain 10,000,000 short tons of K_2O in measured and indicated reserves. Of this, 6,000,000 tons is considered recoverable.

In 1942 the potash-bearing salt deposits of southeastern New Mexico were estimated to contain 75,000,000 short tons of K_2O in beds having a minimum thickness of 4 feet and containing 14 percent or more of K_2O. The estimates were based on core tests, mainly from a half-mile to a mile apart, and on mining experience, and are classed as measured and indicated. In present mining practice, roughly 60 percent of the potash ore is recovered, so that 45,000,000 tons of K_2O may be considered as available. The material now being mined averages 20 percent or more of K_2O.

These two major sources thus contain more than 50,000,000 tons of recoverable potash, equivalent to a supply for more than 60 years at normal peacetime rates of consumption.

Potash salts have been found in widely separated deep borings in the Paradox Basin in eastern Utah, in deposits similar to those in New Mexico, but the deposits are not well enough known to be included in estimates of reserves. The great areas underlain by the salt deposits of Permian age in the Western States have by no means been thoroughly explored, and there is every expectation that other deposits will be found. Possible developments in technology may permit the handling of material now regarded as too low-grade or in layers too thin to mine. There are also large deposits of other minerals, such as those investigated during the First World War, and of polyhalite (hydrated sulfate of potassium, calcium, and magnesium, that represent immense potential sources of potash. The relative cheapness and abundance of the potash salts now being mined, however, may postpone for a good many years the significant utilization of these other resources. Should they be developed and utilized, they might be expected to contribute a total of several hundred million tons.

Chart XXII shows the distribution of potash production and estimated reserves in the United States as of 1943, by States.

Quartz Crystal

By H. M. Bannerman,[88] G. R. Gwinn,[89] and W. H. Waggaman [89]

The industrial demand for quartz crystal is relatively new. To 1925, quartz crystal was used chiefly in ornaments and in making lenses and prisms for some optical instruments. These uses continue, but in recent years they have been far surpassed by the quantities used in making special devices to control the wave frequency in electric circuits, particularly in telephonic and radio communications systems, and in such precision instruments as range and direction finders, sound-detection devices, and seismographs. Quartz was first used for this purpose in submarine-detecting apparatus developed during World War I, and its potential use in radio was demonstrated in 1921. About the middle thirties, the increased complexity and crowding of communication channels made it necessary to establish a system of precise wave-frequency control in radio, and quartz oscillator plates were adopted as a standard device. In 1940 approximately 15 short tons

[88] Geological Survey.
[89] Bureau of Mines.

POTASH

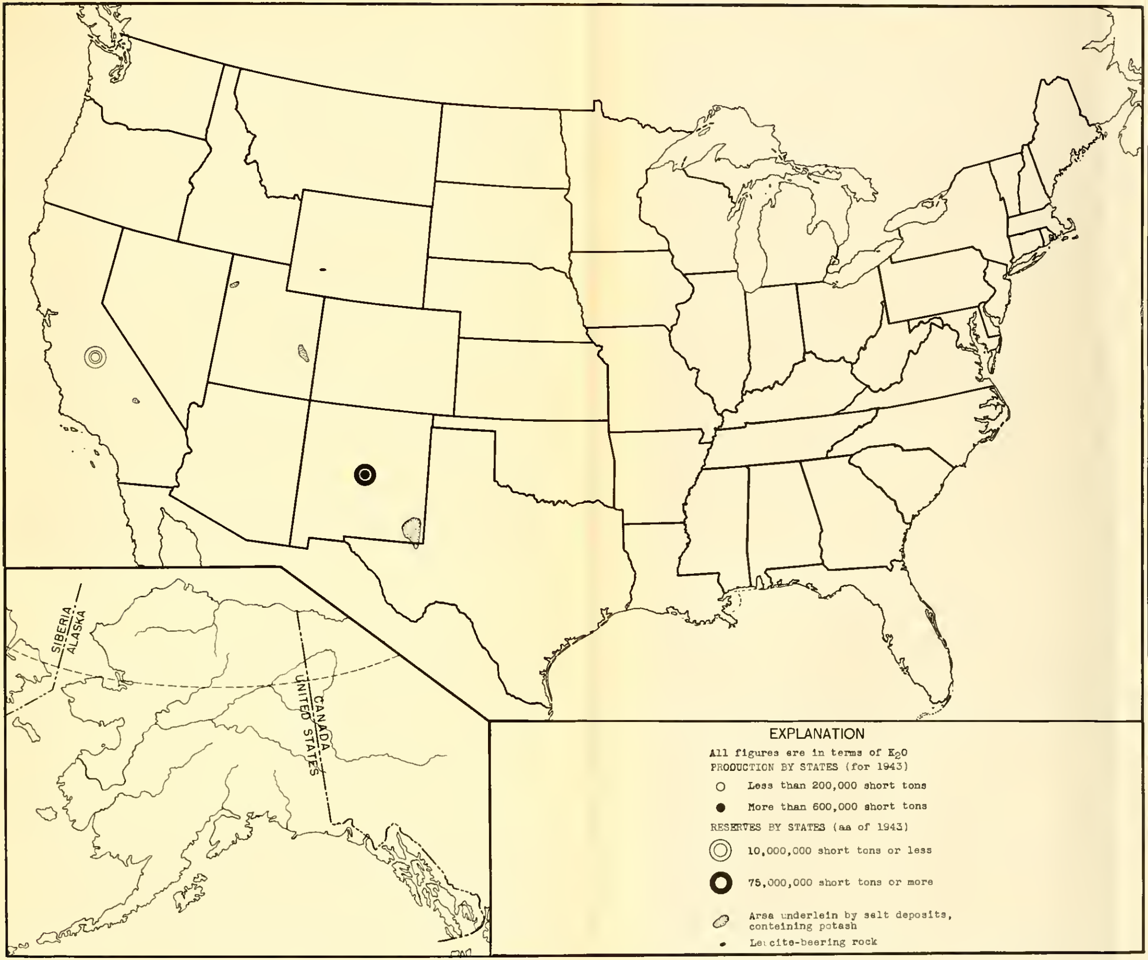

CHART XXII.—Distribution of production and estimated reserves of potash in the United States as of 1943, by States.

of quartz of oscillator quality were used by United States industry, and in 1943 the United States imported 1,678 tons and used almost 800 This large demand probably will drop in postwar years, but it seems likely that to some extent postwar requirements will exceed those of 1940.

According to present specifications, quartz for these special uses must be in individual crystals, transparent, and virtually free from cracks, specks, bubbles, and other defects. These crystals are divided into two general classes by weight, the first being 200 grams and above and the second less than 200 grams. While those weighing at least 200 grams are preferred, crystals under this weight, measuring as little as 2¼ inches parallel to the optic axis and 1 inch in average diameter perpendicular to the optic axis, have been accepted. Crystals bearing one or more natural crystal faces are favored because of the ease with which they can be oriented for cutting. No satisfactory substitute is known. A number of other minerals have equivalent properties but either occur in such small quantities as to be virtually unobtainable, or individual crystals are habitually too small or have other physical limitations that prevent their use. Likewise, some artificial crystals, notably rochelle salts, have some desired properties, but the instability of these compounds under rapidly changing temperatures and their susceptibility to attack by solvents preclude their use.

Despite the fact that quartz is one of the commonest minerals, workable deposits of suitable crystals are few. The United States depends almost entirely upon Brazil for its supply, although small lots have been received from Australia, Colombia, Madagascar, and Portugese East Africa.

Domestic deposits occur in various rocks and as boulders from unknown sources in soil and in stream gravels. The largest known and most promising deposits are in the Ouachita Mountains of western Arkansas, where the crystals occur in quartz veins. A large percentage of the crystals in these deposits is too small to be used under present technological practice, but some quartz of fine grade has been recovered.

Until 1943 domestic production never amounted to more than a few pounds in any one year, although several hundred pounds are said to have been produced during 1917 and 1918 from placer deposits in California. Under the stimulus of high prices and war emergency, about 3 tons, in all, of usable crystals were obtained from a number of localities in the United States during 1943. Of this amount, 5,287 pounds came from Arkansas, 219 from North Carolina, 152 from Virginia, and 208 from California, while the remainder was obtained in small consignments from Alabama, Arizona, Georgia, Idaho, and Nevada. Table 33 lists the imports and consumption from 1933 to 1944. The export figures for 1942, 1943, and 1944 represent reexport of Brazilian crystals to Canada.

TABLE 33.—*Imports, exports, and consumption of quartz crystals, 1933–44*

[In short tons]

Year	Imports	Exports	Consumption	Year	Imports	Exports	Consumption
1933	4		(1)	1939	33		(1)
1934	4		(1)	1940	6		15
1935	3		(1)	1941	1,317		46
1936	11		(1)	1942	1,306	6	341
1937	16		(1)	1943	1,678	56	794
1938	28		(1)	1944	1,150	63	929

1 Data not available.

Reserves

The pockety nature of the quartz deposits discovered to date and the general lack of mining data on deposits of this kind make it impossible to estimate available reserves accurately. No domestic deposits of sufficient size and quality to meet present specifications, even in terms of prewar demand, are known.

Data derived from geological studies and limited mining operations carried on during 1943 suggest that, if the price was high enough, the Arkansas deposits might produce as much as 25 tons of eye-clear quartz annually for about 5 years. Based on 1943 Metals Reserve Company specifications as to weight, approximately 7 percent of this output probably would be grade 1 quality; 3 percent, grade 2; 52 percent, grade 3; and the remainder between 70 and 200 grams in weight.

Should specifications be modified to include crystals weighing as little as 50 to 100 grams, domestic reserves would be increased considerably; but even then, from data at hand, they could not be considered adequate, particularly in time of war.

Salt

By Eugene Callaghan,[90] G. W. Josephson,[91] and O. C. Ralston [91]

Common salt (sodium chloride) is one of the primary necessities of life as well as of industry, and inexhaustible supplies are known to exist in the United States and in the adjacent seas. The chemical industry, which is the largest consumer, is mainly concentrated in the Northeastern States, the Midwest, along the Gulf coast, and in California; in all of these places, there are large resources either of rock salt or salt in sea water. Seventy percent of the annual salt recovery is used by the chemical industry, mainly to produce soda ash, chlorine, bleaches, and chlorates, and also, to a limited extent, dyes, organic compounds, soap, and miscellaneous chemicals. The remainder is used in the food industry, miscellaneous manufacturing, and the home.

Beds of rock salt underlie three large areas—one in New York, Pennsylvania, Ohio, and West Virginia; another confined mainly to Michigan; and the third in Kansas, Oklahoma, Texas, and New Mexico. Although it is not certain that there is a continuous layer of salt throughout any of these areas, most of the deep wells penetrate a bed of salt 200 feet or more thick. Some of the salt produced from subsurface deposits is mined, but most of it is dissolved underground and pumped to the surface as brine.

The great salt beds of the midcontinent region contain the largest quantities of salt of any area in the country, but as the region is not yet highly industrialized, there is relatively little production. The numerous salt domes of the Gulf coast are known because of their relation to accumulations of oil and sulfur. Enormous quantities of rock salt probably are present in the Paradox formation of Colorado and Utah, where it has been found by wells drilled for oil and potash. Saline lake and playa deposits occur in the Great Salt Lake Basin of Utah and in southeastern California. Most of the salt resources are relatively accessible; and production, prices, and costs—compared to those of many commodities—are low.

The growth of the chemical industries is reflected in the increased salt production, which rose from 4,243,000 short tons in 1910 to 15,214,000 short tons in 1943. By comparison, prewar foreign production is estimated at 30,000,000 tons yearly. Consumption approximately equals domestic production; imports average 0.25 percent and exports 1 percent of domestic production in recent years.

Reserves

Even exclusive of sea water, the amount of salt available in the United States is practically astronomic. Preliminary calculation indicates a possible 60,000 billion tons as the inferred reserve. Actually only the part near industrial centers is available for cheap extraction, yet this part may be regarded as adequate to meet requirements for many centuries.

Chart XXIII shows the distribution of salt reserves in the United States.

Silver

By McHenry Moiser,[92] C. E. Needham,[92] and C. F. Park [93]

Silver has been used traditionally for coinage, for monetary stocks, and as a reserve for notes issued by governments and central banks. However, its use in arts and industries is growing rapidly, and now there is a large consumption for photography, bearing metals, electrical conductors and contacts, silverware, jewelry, insignia, dental and medical supplies, and silver solders. During World War II silver was used extensively in the production of many types of equipment and weapons.

Substitutes for silver are rhodium in reflector coatings for searchlights and headlights, platinotype, and photographic printing paper; enamels in dentistry; and tantalum in surgery and laboratory apparatus. The effect of these substi-

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[90] Geological Survey.
[91] Bureau of Mines.
[92] Bureau of Mines.
[93] Geological Survey.

SALT

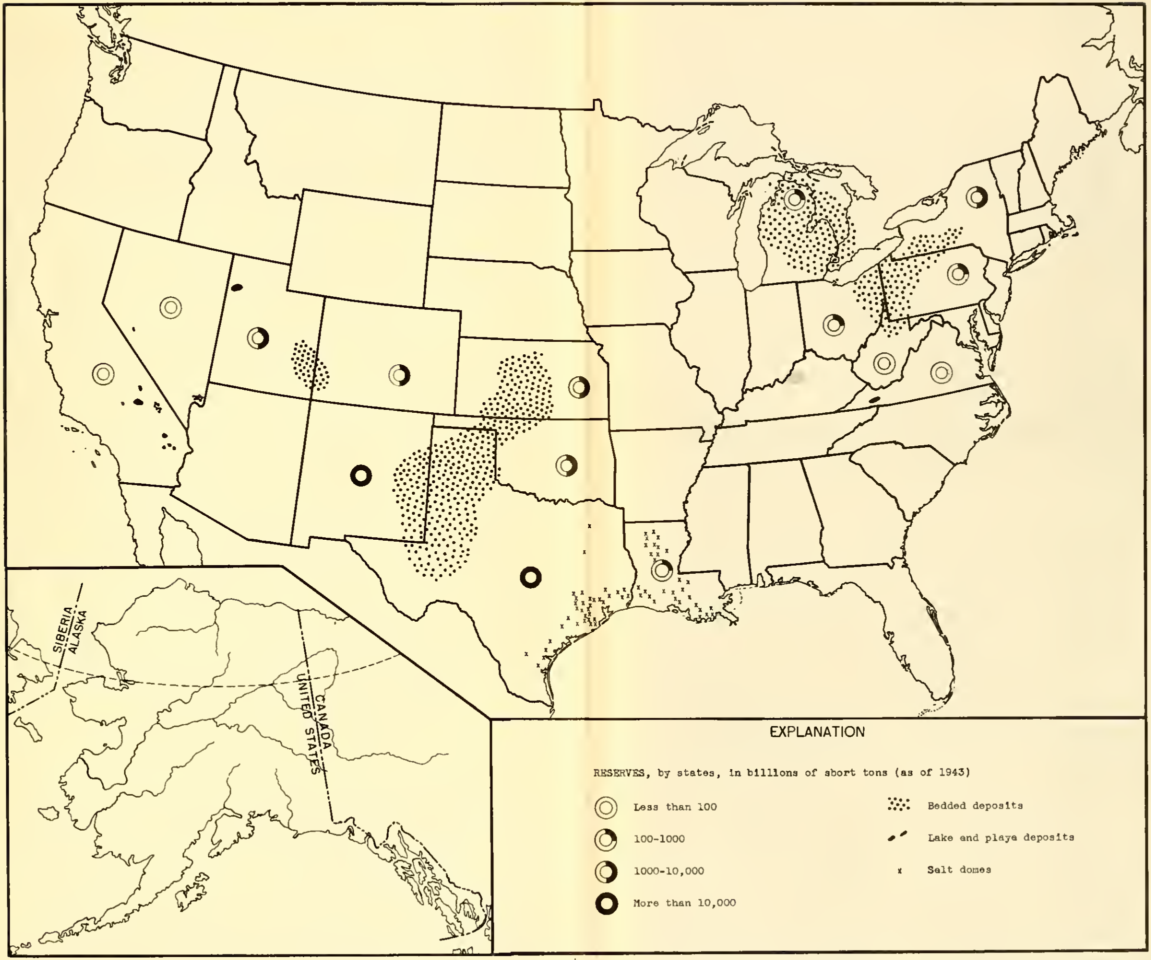

CHART XXIII.—Distribution of estimated salt reserves of the United States as of 1943, by States.

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tutes on reserves is small and was far outbalanced by the tendency during the recent war to use silver in place of more critical and strategic materials, such as tin, copper, chromium, and nickel.

Silver is obtained primarily from the mining of base-metal ores, predominantly copper ores. Moreover, these ores contain most of the silver reserves. In only a few mines—such as those in the Tonopah and Virginia City districts in Nevada and several in the Coeur d'Alene district, Idaho—is silver the principal metal sought. Production of placer silver is negligible. The Western States produce virtually all the silver. A graph illustrating the relation of production and domestic price, as well as the United States percentage of world production and United States net industrial consumption, is shown in figure 31. By net industrial consumption is meant the amount consumed minus scrap and

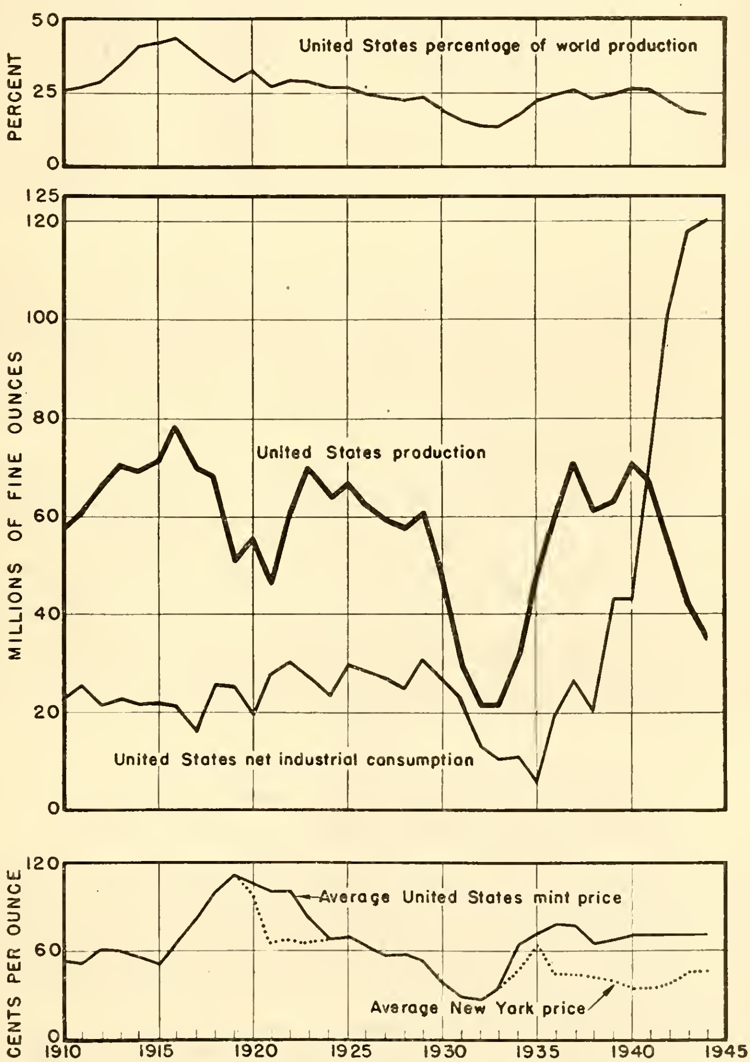

FIGURE 31.—Trends in production, net industrial consumption, and price of silver in the United States, 1910–44. Average New York price coincides with average United States mint price, except for divergencies shown.

re-treated metal. The distribution of silver production, by States, is shown on chart XXIV.

TABLE 34.—*Estimated commercial reserves of silver in the United States as of January 1944, by States*

[In troy ounces]

State	In measured and indicated ores	In inferred ores	Total
Alaska	1,000,000	1,000,000	2,000,000
Arizona	70,000,000	30,000,000	100,000,000
California	25,000,000	15,000,000	40,000,000
Colorado	70,000,000	30,000,000	100,000,000
Idaho	150,000,000	75,000,000	225,000,000
Montana	75,000,000	30,000,000	105,000,000
Nevada	40,000,000	5,000,000	45,000,000
Central States	3,000,000	2,500,000	5,500,000
New Mexico	10,000,000	3,000,000	13,000,000
Oregon	1,000,000		1,000,000
South Dakota	1,500,000	700,000	2,200,000
Utah	100,000,000	20,000,000	120,000,000
Washington	3,000,000		3,000,000
Eastern States	1,200,000	500,000	1,700,000
Total	550,700,000	212,700,000	763,400,000

Reserves

As shown in table 34, the estimated silver reserves of the United States, including Alaska, amounted in January 1944 to about 763,000,000 ounces of recoverable silver available in the ground under present economic and technologic conditions. This is approximately 24 percent of the total monetary stocks of silver held by the United States Government as of January 1, 1944, including bullion, coin, and loans to defense plant corporations. Measured and indicated reserves have been combined in the table because the Government does not have data in sufficient detail to report them separately.

At the 1940 rate of consumption (45,000,000 ounces), the life of the estimated reserves would be about 17 years; but, inasmuch as three-fourths to four-fifths of the silver production is obtained as a byproduct of base-metal mining, silver will continue to be produced as long as base-metal ores are mined. Reserves of silver in lodes comprise one-fifth to one-fourth of the total reserve.

The rate of production of silver depends closely upon the rate of production of copper, lead, zinc, and gold and to a smaller extent on the market and mint price of the metal. As improvements are realized in mining, ore dressing, smelting, and refining, lower-grade ores of these other metals will be extracted so that some of the present subcommercial silver-bearing deposits will be beneficiated. Further discoveries of silver ores and silver-bearing base ores may be expected to contribute substantial amounts to the national reserves in excess of the quantity estimated above.

SULFUR

(INCLUDING PYRITE AND BYPRODUCT SULFUR COMPOUNDS)

By G. W. Josephson,[94] O. C. Ralston,[94] and Ward C. Smith[95]

Sulfur is one of the basic raw materials of modern industry. In elemental form, it has many uses, notably in rubber products and insecticides. Large quantities are consumed in the manufacture of paper. However, over three-fourths of all the sulfur that is consumed in the United States is converted into sulfuric acid before entering its final use. Sulfuric acid is required by almost every industry, but the largest tonnages go into fertilizer, chemical, petroleum, and metallurgical production.

Substitutes for sulfur or sulfuric acid have been developed for only an insignificant part of the consumption. As an example, some plants use hydrofluoric acid instead of sulfuric acid in the manufacture of high-octane gasoline. The special properties of sulfur and sulfur compounds, combined with the abundant, cheap

[94] Bureau of Mines.
[95] Geological Survey.

SILVER

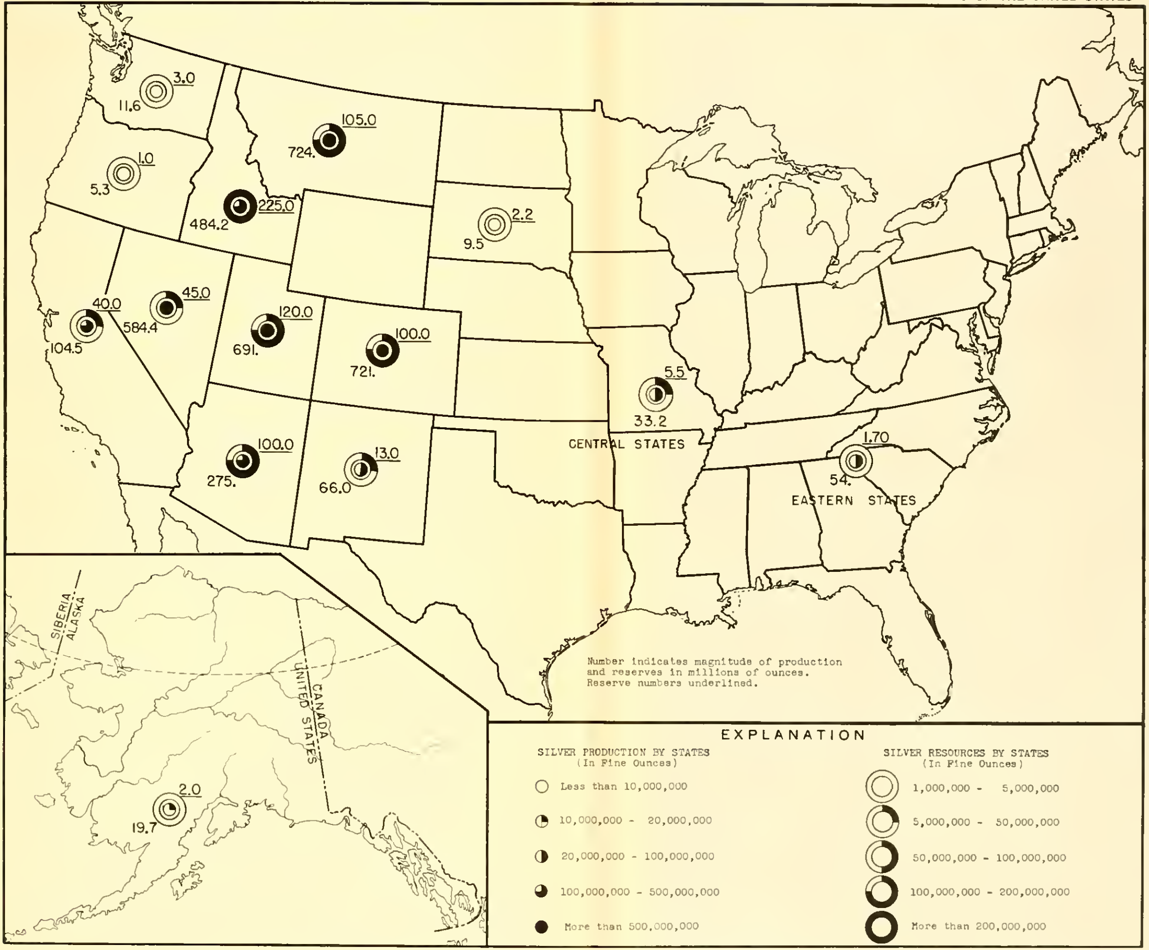

CHART XXIV.—Total production of silver through 1943 and estimated reserves as of January 1944, by States.

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supply that is in prospect for many years, make it difficult for substitutes to compete.

The principal world sources of sulfur are deposits of native sulfur and of pyrite; they supply large quantities of material low in price and inexpensive to process. Each serves those markets in which local conditions give it advantages. The trade term "pyrites" is used for a group of iron sulfide minerals, including the mineral pyrite itself, marcasite, and pyrrhotite.

The recovery of sulfur compounds as byproducts of a variety of industrial operations has been increasing. In the last 5 years the equivalent of about 200,000 long tons of sulfur has been recovered as sulfur chemicals yearly from the gases of copper and zinc smelters, coke ovens, oil refineries, and other industrial plants. Deposits of gypsum and anhydrite (both calcium sulfate) constitute potential sources of great magnitude. In 1942, 78 percent of the domestic

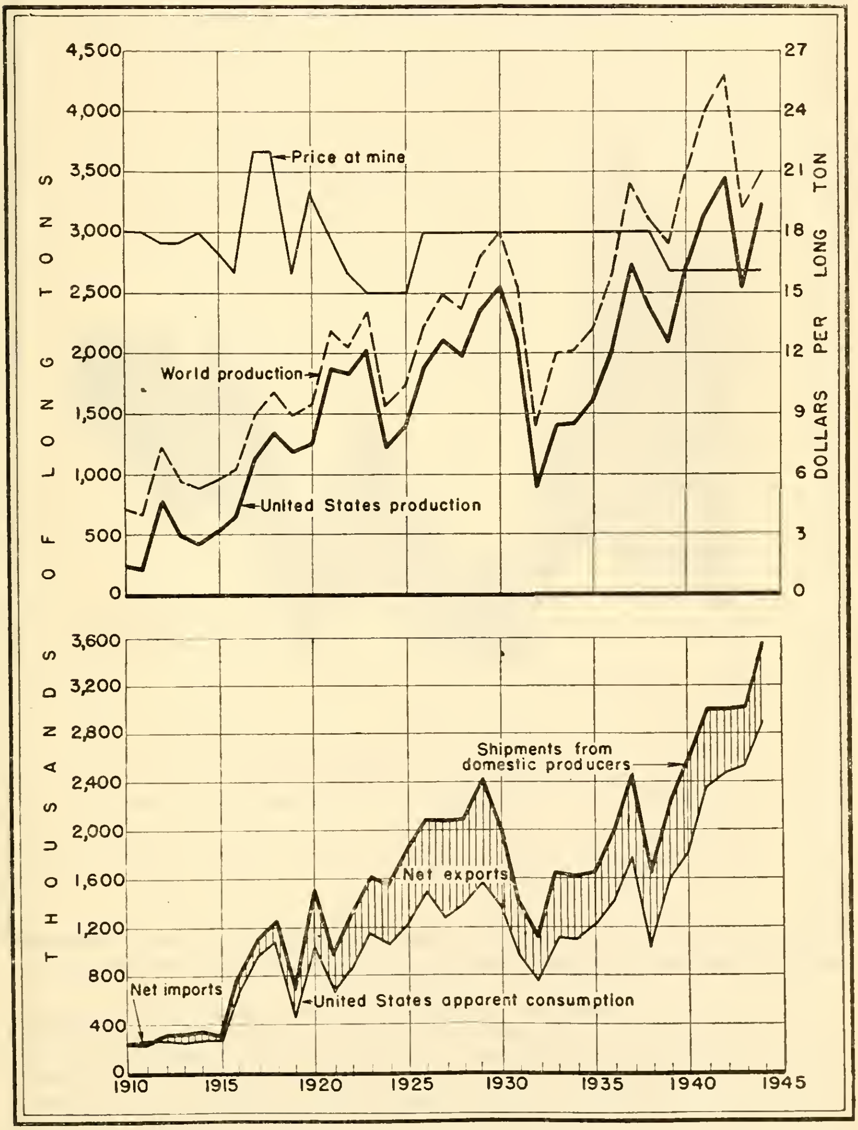

FIGURE 32.—Trends in production, consumption, and price of sulfur in the United States and in world production, 1910–44.

sulfur demand was supplied by native sulfur, 10 percent by domestic pyrite, 8 percent by byproduct sulfur compounds, and 4 percent by imported pyrite.

Not only is the United States self-sufficient in sulfur but has a commanding position in the export market. During the period 1935–39, exports of native sulfur averaged 583,000 tons yearly—27 percent of domestic production. To insure continuous supply for the market, the industry maintains large stock piles of sulfur, which are built up and depleted according to demand.

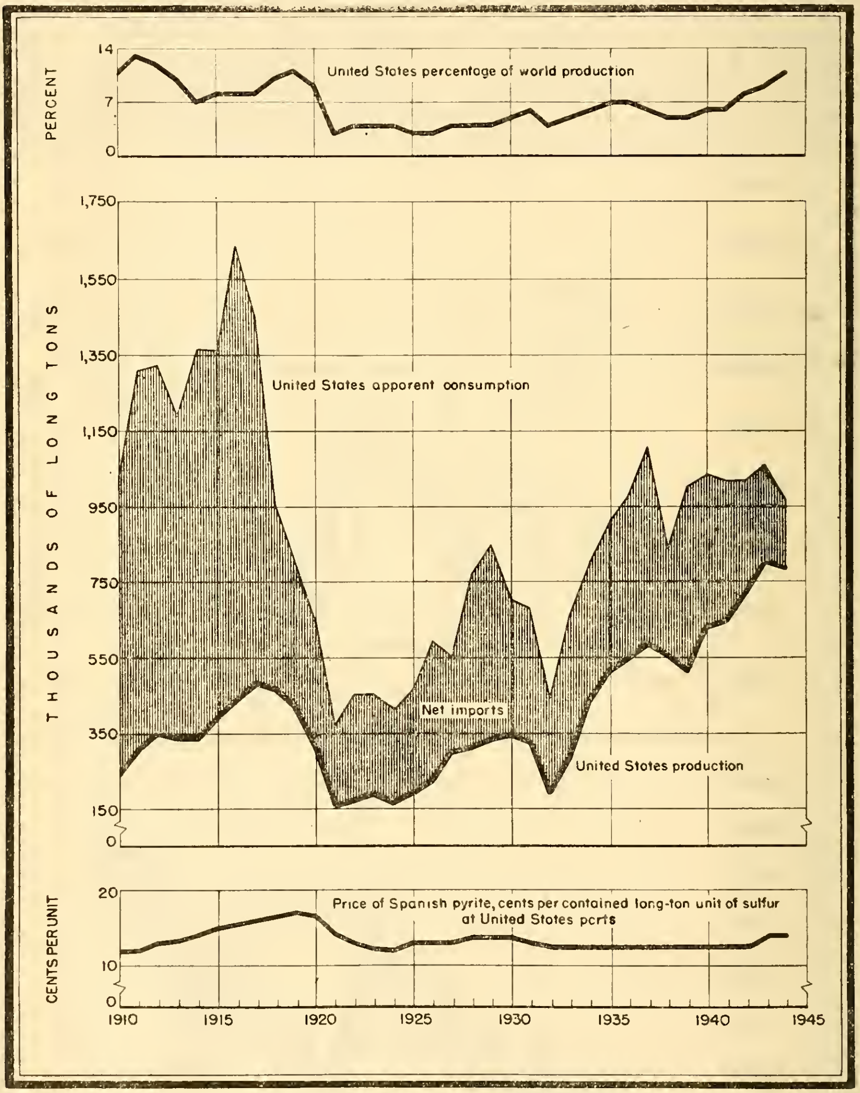

Figure 33.—Trends in production, consumption, and price of pyrite in the United States, 1910–44.

According to local conditions, some consumers find it profitable to use pyrite from domestic sources or imported from Canada or Spain; but, for the Nation as a whole, prices have favored the increased use of native sulfur, even to the exclusion of large quantities of pyrite separated but discarded at many metal and coal mines. In 1944 the United States produced 789,000 long tons of pyrite and 3,218,000 long tons of native sulfur. Recent world production of pyrite has been estimated at about 9,000,000 tons annually, containing 4,000,000 long tons of sulfur, whereas native sulfur output probably totals slightly less than 4,000,000 tons. The relation of consumpion, imports, exports, and prices to production is shown in figures 32 (sulfur) and 33 (pyrite).

SULFUR AND PYRITES

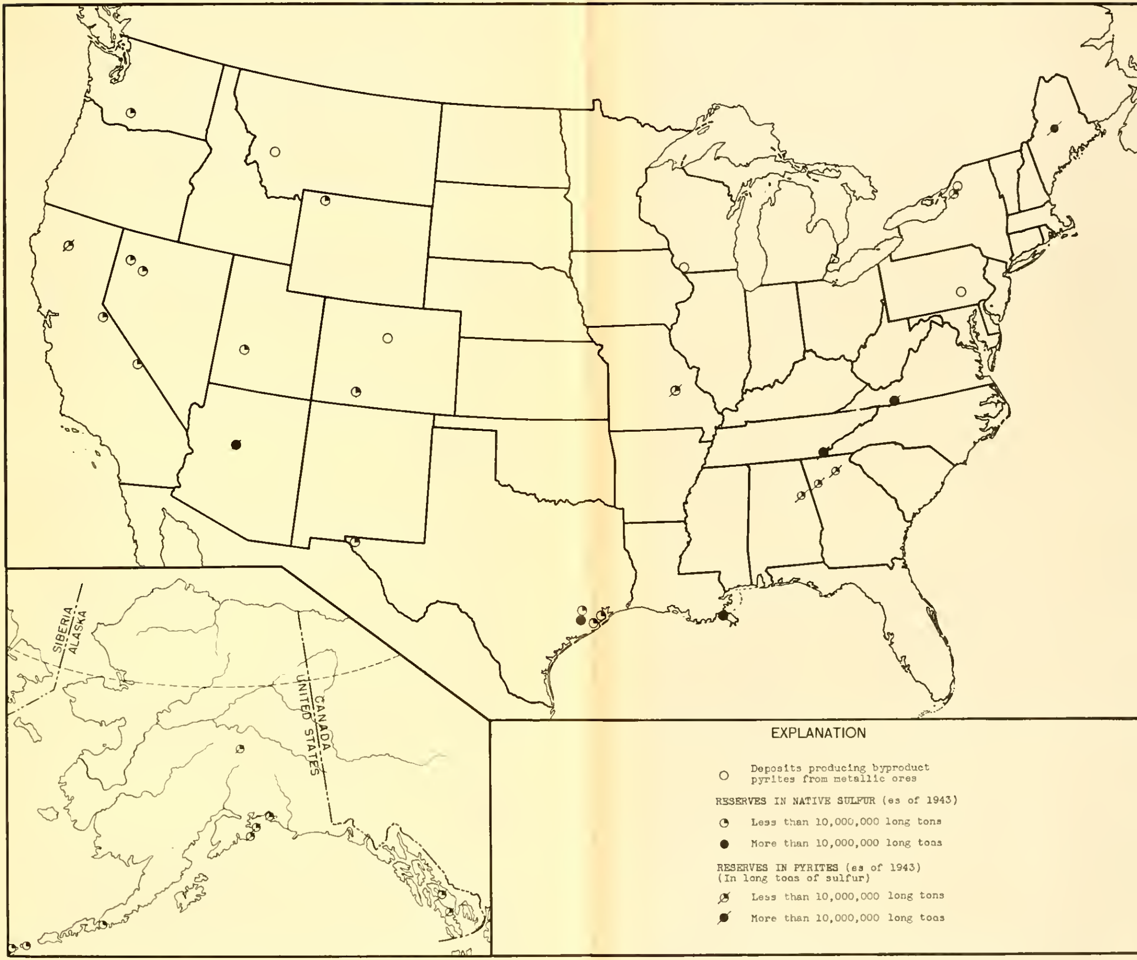

CHART XXV.—Estimated commercial and submarginal reserves of native sulfur and sulfur in pyrites in the United States and Alaska as of 1943, by States.

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The location of domestic sources is shown in chart XXV.

Most of the known native sulfur is in the salt domes of the Gulf coast region. Small volcanic deposits, worked in the past, occur in California and Washington, and unworked deposits of this kind are known in Alaska. Native sulfur accumulates around some hot springs; and, although deposits of this kind have been mined in the Western States, most of them are relatively small.

Two of the largest known domestic pyrite deposits are the United Verde mine at Jerome, Ariz., and the Hornet mine, Shasta County, Calif. Bodies of marcasite, numbering perhaps a hundred, are scattered in Missouri. Pyrrhotite deposits in Tennessee and Virginia are the most productive domestic sources of sulfuric acid from sulfide minerals. Other less well-explored pyrite deposits are known in Maine, New York, Georgia, and Alabama. Much pyrite is recovered as a byproduct in the milling of sulfide ores of copper, lead, and zinc; marcasite and pyrite (coal brasses) are recovered in coal washing.

Reserves

Table 35 lists the reserves of sulfur in known domestic deposits of native sulfur and pyrite, including both the sulfur available under conditions as in 1944 and the additional sulfur that may become available under future demand. Byproduct sources now supply a substantial part of the sulfur and may become more important in future; the estimated reserves from these sources are listed in table 36. Although the reserves in byproduct sources are large, the sulfur only becomes available slowly in quantities determined by the rate at which the main product is made.

TABLE 35.—*Estimated reserves of sulfur in the United States available in deposits of native sulfur and pyrite*

[In long tons of sulfur]

	Available under conditions as in 1944	Additional available in future
Native sulfur:		
Gulf coast region	60,000,000	20,000,000
Western States		2,000,000
Alaska		200,000
Total	60,000,000	22,200,000
Pyrite:		
Arizona (United Verde mine)		35,000,000
California (Hornet mine)	1,000,000	
Maine (Katahdin deposit)		10,000,000
Missouri		1,000,000
New York		3,000,000
Southeastern States	25,000,000	
Alaska		1,000,000
Total	26,000,000	50,000,000
Grand total	86,000,000	72,000,000

TABLE 36.—*Estimated reserves of sulfur available in pyrite and sulfur compounds from byproduct sources in the United States*

[In millions of long tons of sulfur]

Source	Approximate quantity in known deposits	Sulfur recoverable in 100 years at present rates
Deposits of sulfide ores of copper, lead, and zinc:		
Pyrite recoverable in milling the ores	75	6.0
Sulfuric acid and other compounds recoverable from waste gases of smelters	45	20.0
Coal deposits:		
Coal brasses recoverable in washing coal	3,000	.8
Sulfuric acid and other compounds from gases of coking and coal-gas plants	3,000	2.4
Sulfuric acid from stack gases of power plant	3,000	
Sulfuric acid from natural gas and crude petroleum	16	
Deposits of gypsum and anhydrite	(1)	

[1] Virtually unlimited.

For the deposits of native sulfur in the Gulf coast region, the reserves in the two largest deposits—the Boling Dome and the Grand Ecaille Dome—constitute a large part of the reserves classed as available under present conditions. Reserves in the Western States are comparatively small; and although some have produced sulfur in recent years, in terms of the industry as a whole they are considered as available only in the future.

At current production rates, the known deposits of native sulfur have a probable life of at least 30 years. Although the reserves of native sulfur are being depleted more rapidly than those of pyrite, the life expectancy of both is being extended by exploration and by imports of pyrite, as well as by increase in the domestic supply of byproduct sulfur. Byproduct sources are not thoroughly exploited and may be expected to continue to yield large and possibly increasing quantities. In any case, it is generally believed that, even if the Nation's known reserve of native sulfur is not substantially bolstered by future discoveries, other domestic sources will be able to supply its needs, possibly at somewhat higher prices. The total domestic reserves available are so great that, assuming that the technology of recovery shows average improvement, any probable annual requirement could be obtained, from one source or another, for generations.

Tantalum

By H. M. Bannerman,[96] E. F. Fitzhugh, Jr.,[97] and Allan F. Matthews[97]

Tantalum is utilized primarily in the manufacture of radio and radar tubes, as a catalyst for the manufacture of synthetic rubber, and as a constituent of carbide cutting tools. It is also used to make aerial camera lenses, corrosion-resistant chemical equipment, and surgical wire and skull plates. Tantalum can, with some loss in efficiency, be replaced by zirconium in some types of radio tubes, by tungsten and titanium in carbide tools, by ordinary glass in lenses, by platinum in chemical equipment, and by vitallium in skull plates.

Two minerals are sources of tantalum—tantalite and microlite—and they are found almost exclusively in pegmatites and in placers derived from the weathering of pemmatites. Tantalite in its pure state is an iron-manganese tantalate but as found in nature usually contains columbium. The tantalum-rich members of the mineral series are called tantalite and the columbium-rich, columbite. Microlite is essentially a calcium pyrotantalate.

The greater part of past production in the United States has come from the Black Hills of South Dakota, New Mexico (microlite), and Maine. The chief reserves now known are in New Mexico, South Dakota, and Colorado, but smaller deposits have been found in other States, particularly Wyoming, Virginia, Maine, New Hampshire, and North Carolina. The outstanding world sources are Belgian Congo and Brazil. Minor sources include Southern Rhodesia, Nigeria, Uganda, Australia, and Argentina.

Generally, tantalum minerals are distributed sporadically in the pegmatites, and much of the ore extracted to date has come from small, rich pockets. Deposits are known, however, in which the tantalum minerals are widely dispersed in small grains. The recovery of tantalum from deposits of this kind depends upon mechanical concentration, but, generally the grade is too low to support mining operations for tantalum alone. By far the greater part of the domestic tantalum resources, however, is contained in deposits of this low-grade disseminated type.

Consumption of tantalum ore ranged from 1,000 to 75,000 pounds annually from 1921 to 1939 and ascended to a peak of 500,000 pounds in the war year 1943. Imports ranged from zero to 57,000 pounds annually from 1921 to 1939 and reached a high of 837,000 pounds in 1944. Chief sources of imports in recent years have been Belgian Congo, Brazil, and southern Africa. Domestic production was begun as early as 1904, and by the end of 1944 the total had reached about 175,000 pounds. Output has been irregular, reaching a high of 36,000 pounds in 1938 but averaging only 6,000 pounds annually in the period 1918–43. The United States thus depends on foreign sources for most of its supply. Domestic production has in the main been derived as a byproduct from mines operated primarily for feldspar and lithium minerals. The price of tantalum ore (concentrates) varies with the grade. The usual trade specifications call for a combined oxide (Ta_2O_5 plus Cb_2O_5) content of 60 percent, with a minimum of 45 percent as Ta_2O_5 if the ore is to be classed as a tantalum ore. During World War II, how-

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[96] Geological Survey.
[97] Bureau of Mines.

ever, specifications were lowered: To be classed as tantalum ore, the material had to contain, first, at least 40 percent and later 30 percent of tantalum pentoxide Ta_2O_5) and not over 3 percent of tin oxide or 3 percent of titanium oxide. The 1944 Government price was \$2.20 per pound of contained Ta_2O_5 for 40-percent ore plus 7 cents bonus for each percent of Ta_2O_5 above that grade. Thus a 65-percent ore was priced at \$3.95 per pound of Ta_2O_5.

Attempts to recover tantalum minerals by milling have been only sporadic, but milling and laboratory tests indicate that typical ores are amenable to gravity concentration.

Reserves

The classification of tantalum-bearing deposits as commercial or noncommercial must be based more upon the value of the associated minerals than upon that of the tantalum itself, for all operations now yielding tantalum depend to some extent on the recovery of other minerals for a part of the net income. Considered in this light, the estimated reserve of recoverable tantalum in known domestic deposits that can be operated at or near 1944 mineral prices and operating costs is shown in table 37.

TABLE 37.—*Estimated reserves of recoverable tantalum in the United States available under conditions prevailing in 1944*

[In pounds of Ta_2O_5]

Grade of concentrates, percent Ta_2O_5	Estimated recoverable reserves, pounds of Ta_2O_5			
	Measured	Indicated	Inferred	Total
65	0	75,000	50,000	125,000
40–45	0	10,000	60,000	70,000
Total	0	85,000	110,000	195,000

Should demand increase the prices for tantalum or for the commonly associated lithium minerals and feldspar, without corresponding increases in production costs, the amount of workable reserves would be raised considerably. A price increase of 75 percent for tantalum alone would, perhaps, make available an additional 300,000 pounds of high-grade (65 percent) concentrates and 100,000 pounds of low-grade (40 to 45 percent) concentrate.

TIN

By C. E. Nighman[98] and Ward Smith[99]

The major use of tin and one for which no adequate substitute has been found is as a protective coating for other metals, especially on steel in tin plate, from which are formed the tin cans in which processed foods and a host of other products are packed. Tin has numerous other uses. In the immediate prewar period, 1935–39, the percentage distribution of the consumption of newly mined tin in the United States was about as follows: Tin and terne plate 52, solder 16, tubes and foil 9, babbitt 6, bronze 5, tinning 4, and other 8. During World War II the relationships were substantially modified, because of necessary conservation of supply and changed needs. There was, for example, a decline in the average weight of coating on tin plate, a great decrease in use of tin for tubes and foil, and the development and wide use of low-tin solders but a marked increase in the use of tin for bronze. In the postwar period some reverse shifts are to be expected, with a distribution not greatly different from the prewar pattern, although at present it seems as if the quantities used for solder, tubes, and foil will be lower.

Inasmuch as it has been demonstrated that the United States is virtually without tin but is the world's greatest tin user—at the rate of roughly 60,000 to 80,000 long tons of virgin tin a year—it was and is fully dependent on foreign supplies. Before World War II nearly all the tin entered as metal and was received mostly from British Malaya, with smaller but substantial quantities from China, the

[98] Bureau of Mines.
[99] Geological Survey.

Netherlands and its colonies, and the United Kingdom. When the Far East supply was cut off at the end of 1941, the United States was forced to turn to new sources, chiefly Belgian Congo and Bolivia, from which imports were obtained largely in the form of concentrates that were treated at the Government-financed smelter in Texas, which became operative in 1942. In future, new supplies probably will be received in the form of metal from the countries that furnished tin to the United States before the war, unless the peacetime operation of the Government smelter proves to be economically feasible or strategically necessary. In that event, Bolivia probably will be an important source of concentrates, and it may be expected also that a portion of the Far East supply will be obtained in the form of ore.

Tin is one of the highest-rank strategic metals because of its essential uses and the fact that the United States, which normally consumes half the world output, must depend on distant sources of supply. Notwithstanding its relatively high unit price and the great wartime efforts made to develop substitutes, nothing has yet been shown to equal it in most of its uses. Thus it is expected that postwar demand quantitatively will probably be slightly above prewar levels. It should be noted that tin recovered from scrap appears in very small quantity as pure metal; it largely returns to use as an alloy constituent. The quantity of tin available at any time is a direct function of the quantity of virgin or newly mined tin that has entered nondissipative consumption in the past. In other words, needs must be met preponderantly by virgin tin.

Figure 34 shows trends in world production, United States consumption, and the price of tin from 1910 to 1944.

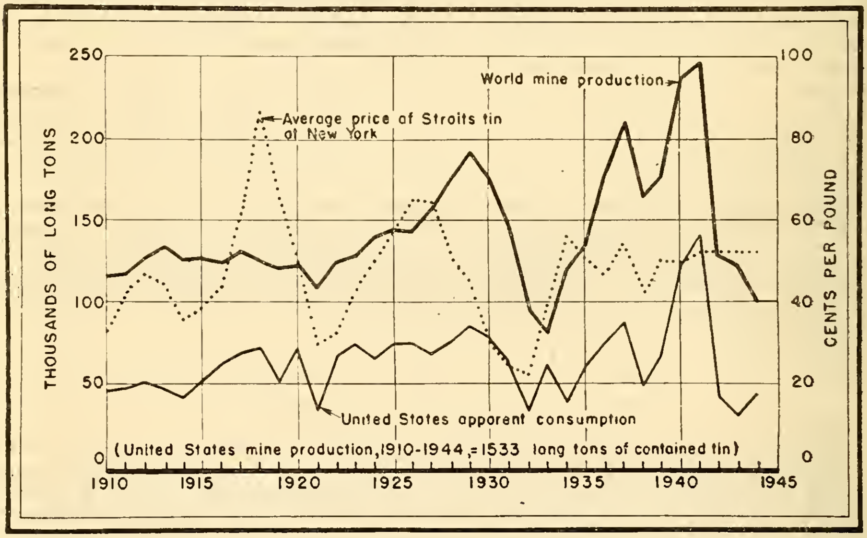

FIGURE 34.—Trends in consumption and price of tin in the United States and in world production, 1910–44.

Reserves

As the result of private explorations at a cost of many millions of dollars and a comprehensive Federal program of exploration from 1939 to 1943, it is clear that known domestic deposits are either too small or too low grade to permit profitable operation or to afford a significant national resource. About nine-tenths of the minuscule domestic production to date has come from Alaska, the remainder from California, the Carolinas, South Dakota, and Texas.

Tin occurrences have been extensively investigated in the Western States as follows: In California in the Gorman district (Kern County), the Cima district (San Bernadino County), and the Temescal district (Riverside County); in Nevada at Majuba Hill (Pershing County) and near Izenhood ranch (northern Lander County); in New Mexico in the Black Range (Catron and Sierra Counties); in Texas at Franklin Mountain near El Paso; in South Dakota in the Black Hills; and in Washington at Silver Hill, Spokane County. In the Eastern States tin-bearing deposits have been explored and tested at Irish

Creek in west-central Virginia; in Coosa and Clay Counties, Ala.; and in the Carolinas, principally in Gaston and Cleveland Counties, N. C.

Tin placers are scattered across Alaska, from just west of the international boundary near the Yukon River to the western end of the Seward Peninsula. The principal areas are in the York district of the Seward Peninsula and in the central part of the Yukon Valley. A little lode tin on the Seward Peninsula is believed to be recoverable at extremely high cost.

Domestic reserves of tin that can be recovered under normal conditions are negligible. Total reserves of all classes of ore are estimated to contain not more than 7,000 short tons of metallic tin, of which 2,000 tons is in the United States and 5,000 tons in Alaska. More than half of these reserves are inferred, the figures for the United States and Alaska being, respectively, 1,600 and 3,000 tons of contained tin. It is to be noted that the total reserve is equivalent to less than 2 months' needs for virgin tin at the sharply restricted consumption rate of 1943.

Titanium

By Allan F. Matthews,[1] O. C. Ralston,[1] and C. S. Ross [2]

Titanium is derived from the minerals ilmenite, an oxide of titanium and iron, and rutile, the dioxide of titanium.

About 95 percent of the ilmenite supply is used in manufacturing titanium dioxide white pigments for paint, paper, rubber, leather, ceramics, plastics, linoleum, printing ink, textiles, cosmetics, and soap. Titanium white paints are noted for a high degree of covering power, brightness, whiteness, and durability. Minor quantities of ilmenite are used in making ferrotitanium alloy and fluxes for the steel industry. White lead and lithopone can substitute for titanium pigments, and other ferro-alloys can replace ferrotitanium.

Rutile is used primarily in welding-rod coatings. The second largest use is in making ferrotitanium. Titanium is added to a number of nonferrous alloys, particularly aluminum, to increase their strength and ductility. Rutile is also used in materials for smoke screens, ceramics, and carbide cutting tools. In virtually all applications, rutile can be replaced by the more plentiful, though more expensive, titanium dioxide extracted from ilmenite.

There is no scrap recovery of titanium.

Ilmenite consumption in the United States rose from some 25,000 short tons in 1930 to over 200,000 tons in 1938 and 380,000 tons in 1945. The bulk of these requirements normally have been met by imports from India, but that source became virtually unavailable during World War II. Domestic production, which never exceeded 25,000 tons yearly until after 1941, was thereby spurred to over 300,000 tons in 1945, largely as a result of developing the Sanford Lake titaniferous (ilmenite-bearing) magnetite deposit at Tahawus, N. Y. Postwar domestic output of ilmenite is expected to remain at a high level, although it may recede somewhat below the wartime peak if high-grade foreign ores return to the market in volume. The nominal price of ilmenite (60 percent of TiO_2, f. o. b. Atlantic seaboard) was $10 per long ton in the 1930's, but demand boosted it to $18 in 1940 and to $28 in 1941, where it remained as of 1944.

Rutile consumption in the United States exceeded 1,000 short tons annually first in 1935, climbed to 6,000 tons in 1941 and over 17,000 tons in 1943, and receded to 10,000 tons in 1945. Domestic production from Arkansas, Florida, and Virginia reached 3,000 tons by 1941 and up to that time had supplied United States consumers with most of their needs. Expanded demand during World War II, however, depended principally on greatly augmented imports from Australia and Brazil. Doubling of mill capacity raised domestic production in 1945 to 7,000 tons, which, partly due to an expected decline in foreign entries, again equaled imports. The nominal price of rutile (94 percent of TiO_2) was 8 to 10 cents a pound during the past decade.

There is no tariff on ilmenite or rutile, but 30 percent ad valorem is levied on titanium pigments and compounds and 15 per cent on ferrotitanium.

Reserves

Estimated reserves in titanium deposits workable under economic and technologic conditions such as those of 1944, at known deposits in the United States, total 17,478,000 short tons of ilmenite and 814,000 tons of rutile. Details by States and classes of ore are shown in table 38. The immediate postwar demand

[1] **Bureau of Mines.**
[2] **Geological Survey.**

for titanium—certain to be considerably greater than the prewar market—is expected to require 350,000 tons of ilmenite and about 7,000 tons of rutile annually. At this rate of consumption (assuming no imports and assuming continued capacity to produce at that rate), the specified reserves would provide ilmenite for 50 years and the rutile for 116 years. At peak wartime rates of consumption, both types of titanium reserves would last about 45 years.

In addition to these currently exploitable reserves, there are large bodies of titaniferous magnetite (containing 2 to 22 percent of TiO_2) in Colorado, Minnesota, Rhode Island, and Wyoming. Unlike the titaniferous magnetite now mined on a large scale at Tahawus, N. Y., the material at Iron Mountain, Wyo., and most other occurrences contain ilmenite and magnetite combined chemically or in such small crystals or complex intergrowths that current milling practices cannot yield a high-titanium product. An additional potential source of titanium is the red-mud residue (7 to 12 percent of TiO_2) from treating bauxite for alumina. These two potential sources are so vast that they very materially buttress the currently exploitable titanium reserves enumerated above.

Chart XXVI shows the distribution of the known titanium resources of the United States.

TABLE 38.—*Estimated reserves of titanium in the United States as of 1944*

State, and class of ore	Ore		Ilmenite or rutile (short tons)	
	Short tons	TiO_2, percent	Gross weight	TiO_2 content
Ilmenite:				
California	250,000	18.0	100,000	45,000
Florida	66,700,000	.84	1,000,000	560,000
New York	12,550,000	16.72	4,750,000	2,090,000
North Carolina	1,000,000	35.0	778,000	350,000
Virginia	26,000,000	19.25	10,850,000	5,000,000
Total	106,500,000		17,478,000	8,045,000
Measured			1,786,000	785,000
Indicated			11,680,000	5,440,000
Inferred			4,012,000	1,820,000
Total			17,478,000	8,045,000
Rutile:				
Arkansas:				
Indicated	1,500,000	3.3	52,000	50,000
Inferred	750,000	2.6	21,000	20,000
Total	2,250,000		73,000	70,000
Florida:				
Indicated	73,600,000	.5	368,000	350,000
Inferred	41,000,000	.5	210,000	195,000
Total	114,600,000		578,000	545,000
Virginia:				
Indicated	2,000,000	3.0	63,000	60,000
Inferred	3,330,000	3.0	100,000	95,000
Total	5,330,000		163,000	155,000
Total, United States	122,180,000		814,000	770,000
Measured				
Indicated			483,000	460,000
Inferred			331,000	310,000
Total			814,000	770,000

TUNGSTEN

By H. W. Davis,[3] M. E. Dorr,[4] Albin C. Johnson,[3] and T. B. Nolan[4]

The chief use of tungsten is in the manufacture of cutting tools, most of which are made of high-speed steel containing about 18 percent of tungsten, 4 percent of chromium, and 1 percent of vanadium. Smaller quantities of tungsten are used in the manufacture of armor-piercing projectiles, magnet steels, valve steels,

[3] Bureau of Mines.
[4] Geological Survey.

UNITED STATES DEPARTMENT OF THE INTERIOR
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TITANIUM

MINERAL RESOURCES OF THE UNITED STATES

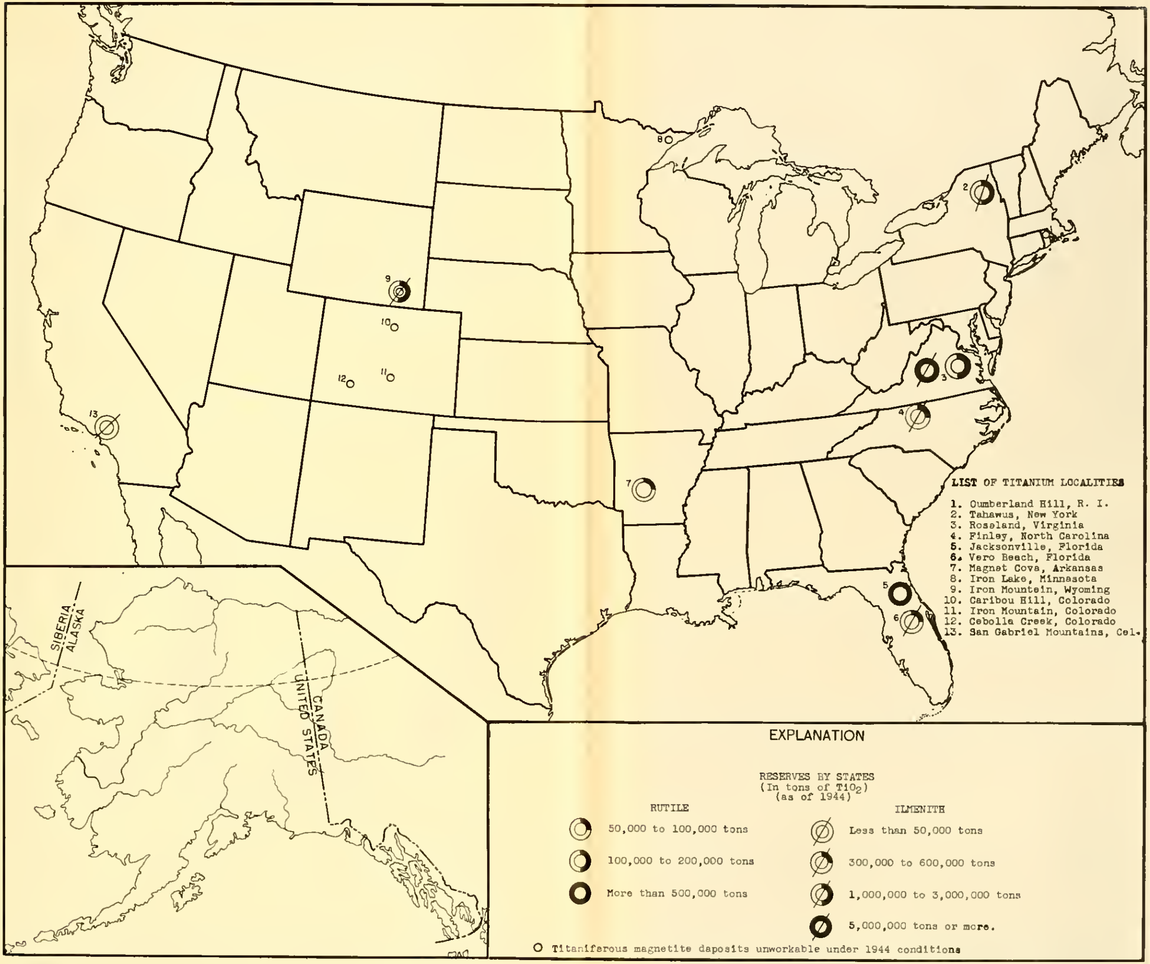

CHART XXVI.—Distribution of titanium reserves of the United States as of 1944.

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and gun liners. Molybdenum-tungsten high-speed steels, which contain 1 to 2 percent of tungsten and 5 to 10 percent of molybdenum, have many successful applications. Minor amounts of tungsten are used in lamp and radio-tube filaments, X-ray targets, and electrical contact points. Tungsten salts are used in the chemical, pigment, and tanning industries.

Tungsten production in the United States since 1910 has yielded only about 40 percent of domestic requirements. Figure 35 shows trends in production, apparent consumption, and price in the United States from 1910 to 1944.

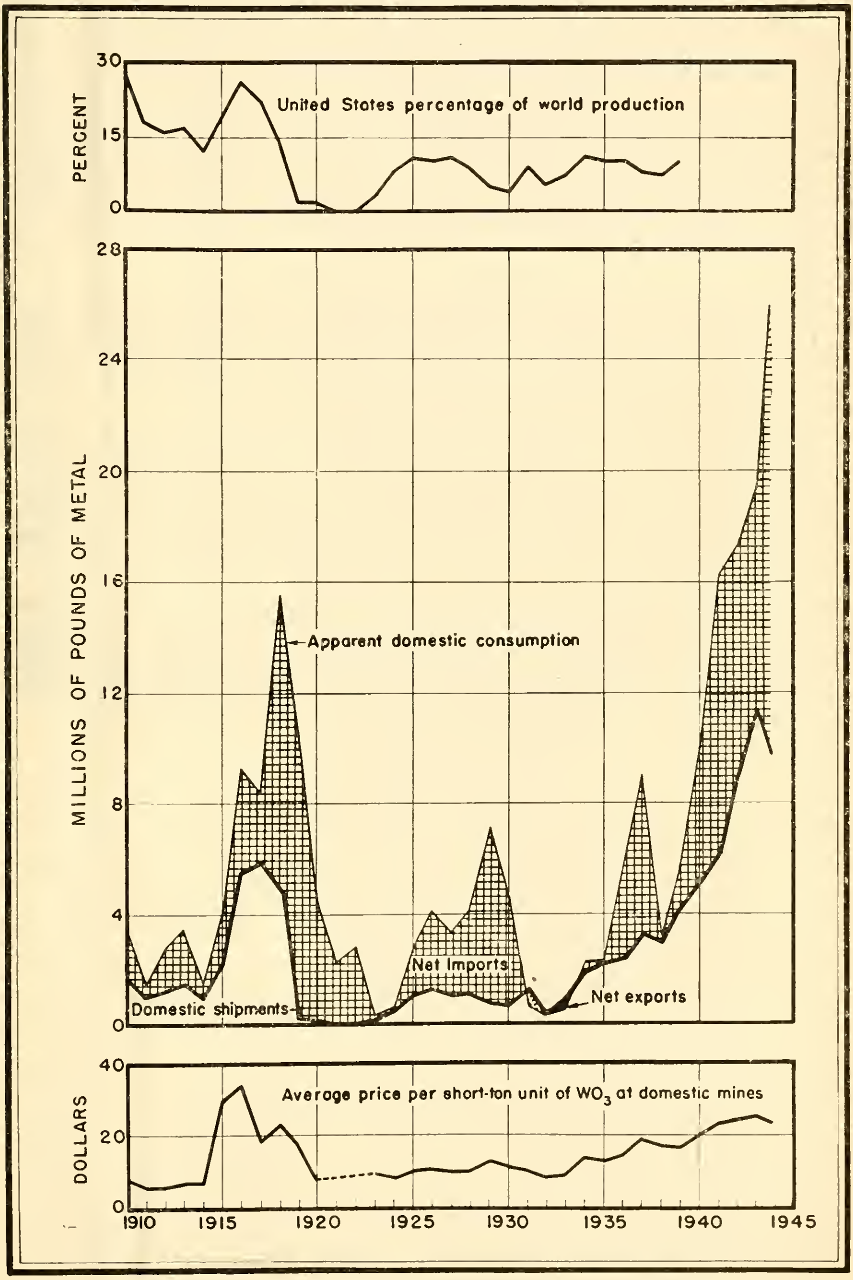


FIGURE 35.—Trends in tungsten industry of the United States, 1910–44.

The greater part of domestic resources of tungsten is in the Western States, notably in California, Nevada, and Idaho; the hübnerite-bearing veins in Vance County, N. C., and Mecklenburg County, Va., constitute the only tungsten deposits of economic importance in the Eastern States. The location and relative importance of the principal tungsten deposits of the United States and Alaska are shown on the accompanying map, chart XXVII. Symbols showing past production of individual districts are not shown on the map. As a consequence, some deposits, such as those in the Atolia district, California, and Boulder County district, Colorado, which are nearing exhaustion, appear relatively unimportant on the map, although both were responsible for a large part of past production. The deposits of Pine Creek, Calif., Ima, Idaho, and Osgood Range, Nev., with a low past-production record, occupy a more important position in the present resource picture. The deposit at Yellow Pine, Idaho, discovered in 1941, was the most important single source of domestic tungsten production from 1942 through 1944.

Prior to World War II, the principal sources of imported tungsten were China, Indochina, Burma, and Portugal. During the war, a substantial part of the imports came from South America, principally from Bolivia, with notably increased amounts from Brazil in 1944, owing to newly discovered scheelite deposits. Imports from China were resumed and continued at a surprising rate through 1943 and into 1944.

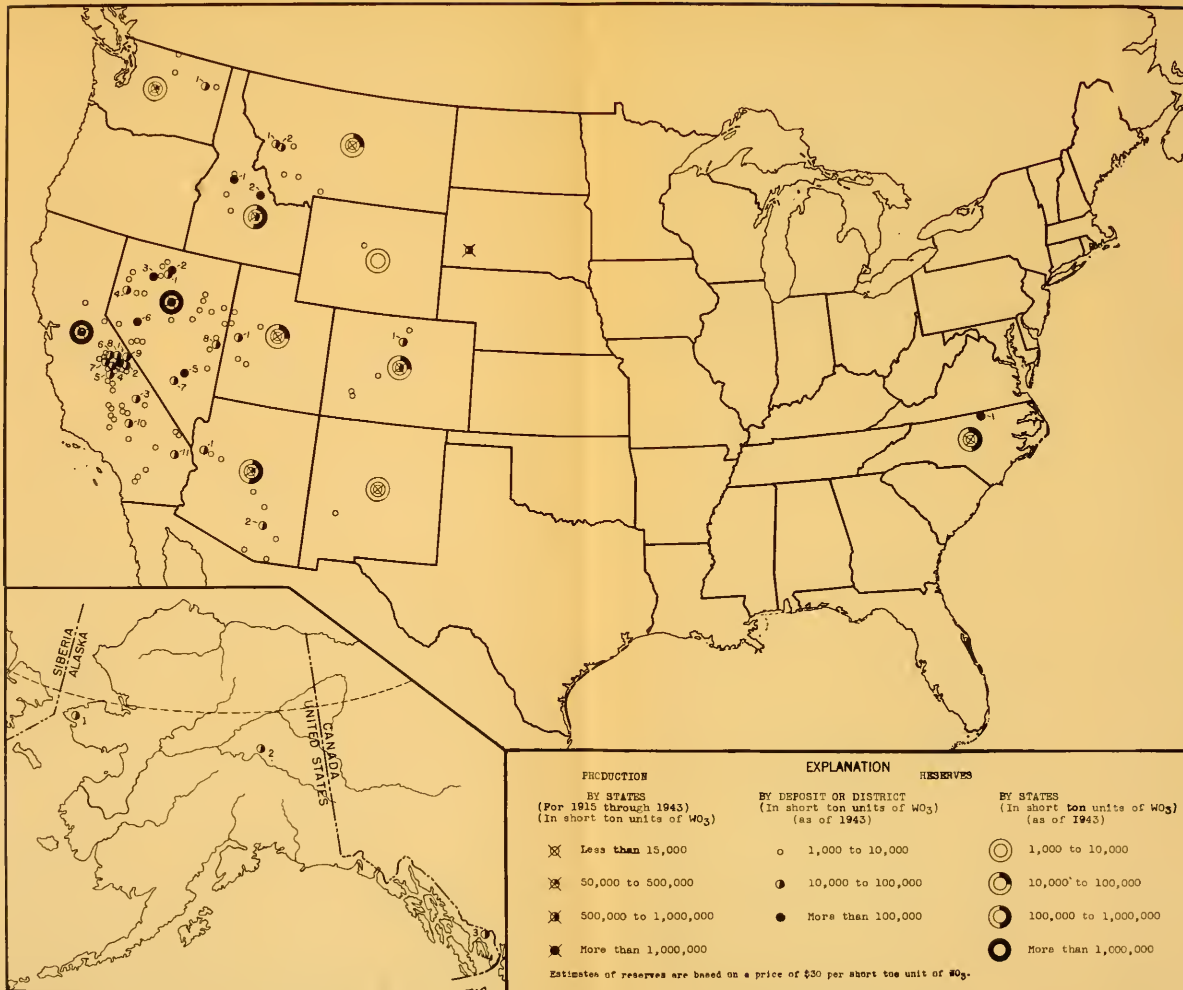
Reserves

Reserves of tungsten-bearing material estimated to be present in known deposits or districts in the continental United States are shown in table 39. The reserves have been calculated on the basis of material that would be commercially profitable at $30, $24, and $16 per short-ton unit. The $30 price was the maximum premium price allowed by the Metal Reserve Company during the war to certain producers; $16 is a representative prewar price.

In the United States, the price of tungsten ore is based upon the units of tungstic oxide (WO_3) per short ton. A "short-ton unit" is equivalent to 20 pounds of WO_3; ore containing 1 percent of WO_3 contains one unit to the ton. National statistics are often expressed in terms of pounds of contained metallic tungsten, 15.86 pounds being eqivalent to one short-ton unit. Reserve estimates are given here in short-ton units of WO_3, with the approximate equivalent in pounds of contained metallic tungsten; gross and recoverable contents of the reserves are shown also.

In addition to the reserves shown in the table, residual or placer-type deposits may contain about 500,000 units of WO_3 (about 7,900,000 pounds of contained tungsten), which probably cannot be recovered profitably even at a price of $30 per unit of WO_3. Furthermore, 1,000,000 units or WO_3 are estimated to be contained in large- low-grade deposits and might be made available at a price somewhat above $30 per unit under conditions of large-scale operation.

TUNGSTEN



PRINCIPAL TUNGSTEN DEPOSITS

ARIZONA
1. Boriana, Mohave County
2. Maudina-Morning Star, Pinal County

CALIFORNIA
1. Pine Creek, Tungstar, and Adamson, Inyo County
2. Tungsten Hills, Inyo County
3. Darwin, Inyo County
4. West slope of Sierra Nevada, Fresno County
5. Garnet Dike, Fresno County
6. Strawberry, Madera County
7. West slope of Sierra Nevada, Madera County
8. Scheelore, Mono County
9. Black Rock, Mono County
10. Atolia, Kern and San Bernardino Counties
11. Old Woman Mountains, San Bernardino County

COLORADO
1. Boulder County

IDAHO
1. Yellow Pine, Valley County
2. Ima, Lemhi County

MONTANA
1. Argo mine, Granite County
2. Henderson Gulch, Granite County

NEVADA
1. Golconda, Humbolt County
2. Osgood Range, Humbolt County
3. Mill City, Pershing County
4. Nightingale, Pershing County
5. Tem Piute, Lincoln County
6. Rawhide, Mineral County
7. Oak Spring, Nye County
8. Minerva, White Pine County

NORTH CAROLINA
1. Bamme, Vance County (and Mecklenburg County, Virginia).

UTAH
1. House Range, Millard County

WASHINGTON
1. Germania, Stevens County

ALASKA
1. York
2. Fairbanks
3. Hyder

CHART XXVII.—Distribution of estimated resources of tungsten in the United States and Alaska, by States and districts, and of total production through 1943, by States.

TABLE 39.—*Estimated tungsten reserves of the United States as of 1943, at $30 or less per short-ton unit of WO_3*

Price per short-ton unit	Measured		Indicated		Inferred		Total	
	Gross	Recoverable [4]	Gross	Recoverable [4]	Gross	Recoverable [4]	Gross	Recoverable
In short-ton units of WO_3:								
$16 or less [1]	300,000	216,000	800,000	576,000	1,400,000	1,008,000	2,500,000	1,800,000
$16 to $24 [2]	500,000	360,000	1,300,000	936,000	900,000	648,000	2,700,000	1,944,000
$24 to $30 [3]	600,000	432,000	2,000,000	1,440,000	2,500,000	1,800,000	51,000,000	3,672,000
Total	1,400,000	1,008,000	4,100,000	2,952,000	4,800,000	3,456,000	10,300,000	7,416,000
In pounds of contained tungsten:								
$16 or less [1]	4,758,000	3,425,800	12,688,000	9,135,300	22,204,000	15,986,800	39,650,000	28,547,900
$16 to $24 [2]	7,930,000	5,709,500	20,618,000	14,844,900	14,274,000	10,277,300	42,822,000	30,831,800
$24 to 30 [3]	9,516,000	6,851,500	31,720,000	22,838,400	39,650,000	28,548,000	80,886,000	58,237,900
Total	22,204,000	15,986,900	65,026,000	46,818,600	76,128,000	54,812,100	163,358,000	117,617,600

[1] Lowest tungsten content of crude ore included in estimates, 0.8 percent of WO_3; average grade, 1.5 percent; minimum size of deposit considered, 10,000 units of WO_3.
[2] Lowest tungsten content of crude ore included in estimates, 0.6 percent of WO_3; average grade 1.2 percent; minimum size of deposit considered, 5,000 units of WO_3.
[3] Lowest tungsten content of crude ore included in estimates, 0.5 percent WO_3; average grade 0.8 percent; minimum size of deposit considered, 500 units of WO_3.
[4] Mining recovery estimated at 90 percent; milling recovery estimated at 80 percent.

Vanadium

By R. P. Fischer,[5] Albin C. Johnson,[6] and C. E. Nighman [6]

Vanadium is employed chiefly as an alloying metal in the steel industry, where it imparts toughness, hardness, strength, and fatigue resistance to alloy steels. It is used also to a minor extent as a purifying agent in the manufacture of steel. Over 80 percent of the vanadium consumed is used in the form of ferrovanadium. Other applications, which normally represent only a few percent of the total vanadium requirements of the United States, include the manufacture of catalysts for use in the chemical industries, chemicals, and nonferrous metal alloys. There is no entirely satisfactory substitute for vanadium in the manufacture of alloy steels, such as, for example, spring steels, although titanium and molybdenum have been used to a limited extent.

Before World War II (1935–39) the United States produced an average of 555 short tons of vanadium per year and consumed about 1,000 tons. The domestic output comprised approximately 25 percent of the world total. As a result of war demands, gross domestic production increased to a peak of nearly 2,800 tons in 1943, which was equivalent to three-quarters of domestic requirements and 60 percent of the estimated world output. Figure 36 shows the trends in production, imports, and price in recent years.

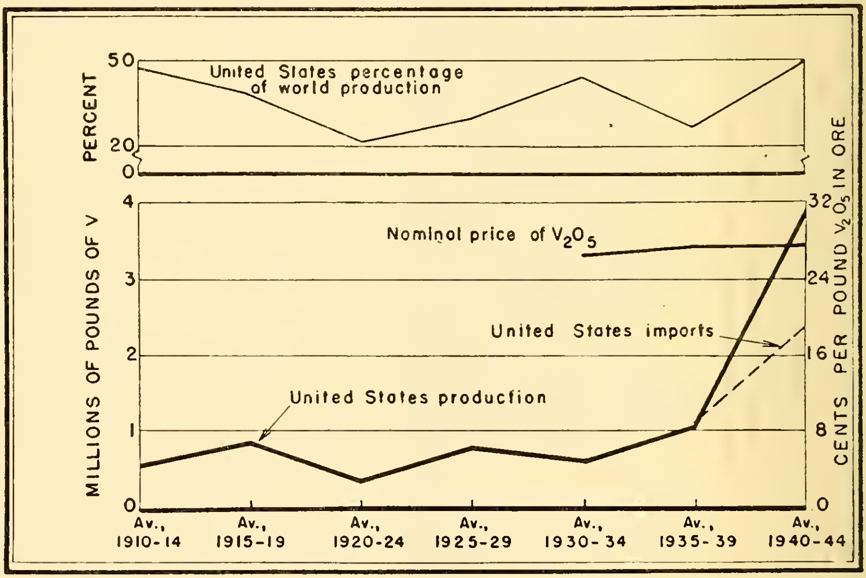


FIGURE 36.—Trends in the production, imports, and price of vanadium oxide in ore in the United States, 1910–44.

The principal world sources of vanadium, listed in order of production, have been the deposit of vanadium sulfide in Peru, the deposits of vanadium-bearing sandstone in the United States, and the vanadate deposits in northern Rhodesia and southwest Africa. Minor amounts of vanadium have been obtained from other vanadate deposits, from asphaltites and the ash of certain oils and coals, as a byproduct from phosphate rocks, and from certain iron ores and bauxites.

Reserves

The vanadium-bearing sandstone deposits are widely distributed in adjacent parts of Colorado, Utah, Arizona, and New Mexico (see chart XXVIII), and they have yielded about 90 percent of the domestic vanadium production. The average grade of ore mined in recent years ranged from 1½ to 2 percent V_2O_5. Individual deposits have a wide range in size, but most of them are small; many contain only a few hundred tons of ore each, though some contain many thousand

[5] Geological Survey.
[6] Bureau of Mines.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY AND BUREAU OF MINES

VANADIUM

MINERAL RESOURCES OF THE UNITED STATES

LIST OF VANADIUM LOCALITIES

Sandstone deposits:
1. Vanadium-bearing sandstone region, Colorado, Utah, Arizona, and New Mexico.

Vanadiferous shale and phosphate region:
2. Vanadiferous shale, Idaho and Wyoming.
3. Vanadiferous phosphate, Idaho and Wyoming.
4. Camp Floyd, Utah.

Vanadate deposits:
5. San Bernardino County, Calif.
6. Goodsprings, Nev.
7. Mammoth, Ariz.
8. Cutter, N. M.
9. Magdalena, N. M.

Titaniferous magnetite:
10. Iron Mountain, Colo.
11. Caribou, Colo.
12. Iron Mountain, Wyo.
13. Iron Lake, Minn.
14. Northwestern North Carolina.
15. Northern New Jersey.
16. Lake Sanford, N. Y.
17. Split Rock, N. Y.
18. Iron Mine Hill. R. I.

Green Mica:
19. Clay, Coosa, and Chilton Counties, Ala.

CHART XXVIII.—Distribution of total production of vanadium through 1943, by deposits or districts, and estimated commercial and submarginal reserves in the United States as of 1943.

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tons. On the basis of geologic studies, the total amount of vanadium contained in these deposits is thought to be large, but because of sporadic local distribution of the deposits and their range in size, the practice of operators is to extend exploration and development only a relatively short distance ahead of mining faces, and for this reason reserves in the usual sense are relatively small. An estimate of available reserves, including inferred reserves which will probably be found with continued mining, and which perhaps can be mined profitably under conditions prevailing in 1943, total several years' supply at the 1943 rate of mining.

Some base metal and previous metal deposits in southwestern United States contain small quantities of vanadates of lead, copper, and zinc. As the vanadates are irregularly distributed in these deposits and the grade of the ore is low, they have been produced only as a byproduct and in a desultory fashion. It is unlikely that these deposits will yield significant amounts of vanadium either under peacetime or wartime conditions.

Phosphate rock, mined at Conda, Idaho, for conversion to superphosphate, contains about 0.30 percent of V_2O_5. Since 1941 some of this vanadium has been recovered as a byproduct. Reserves of phosphate rock in Idaho and Wyoming are large, and it is likely that this source will continue to yield vanadium in the future. In addition many millions of tons of vanadiferous shale associated with the phosphate rock contain from 0.70 to 1.30 percent of V_2O_5. No vanadium has been produced from these deposits and it is not certain that it can be produced profitably under conditions such as those prevailing recently. Presumably much vanadium could be obtained from this source under more favorable prices and improved technology.

Vanadiferous shale similar to that in Wyoming and Idaho has been found in the Camp Floyd district, Utah, but the grade is low and the tonnage of indicated reserves small.

Most titaniferous magnetite deposits contain some vanadium, the amount ranging from 0.1 to 0.5 percent of V_2O_5. Although the grade is so low that these deposits cannot be worked for vanadium alone, they represent a large reserve of vanadium, some of which might be obtained as a byproduct. Perhaps the most readily available source is the Lake Sanford, N. Y., deposit, which is now being worked for titanium. The magnetic iron-ore concentrates being produced from this ore contain about 0.7 percent of V_2O_5, and it has been reported that a plant for the extraction of vanadium is under consideration. Most of the other titaniferous magnetite deposits in the United States appear to be less favorable as a possible source of byproduct vanadium, either because of the complex metallurgy involved in their treatment or because the vanadium content is too low to permit profitable extraction.

Vanadium-bearing green mica is associated with flake-graphite deposits in Alabama. The average vanadium content of the micaceous rocks and the tonnage of the material present have not been determined.

Zinc

By E. F. Fitzhugh, Jr.,[7] E. T. McKnight,[8] and A. L. Ransome[7]

Zinc is marketed in six grades—Special High Grade, High Grade, Intermediate, Brass Special, Selected, and Prime Western—in descending order of purity. The principal uses include galvanizing of iron and steel, brassmaking, zinc-base alloys for die castings and stamping dies, rolled-zinc products, and zinc pigments and chemicals. Substitutes for zinc include lead for the coating of iron and steel and in pigments, cadmium for plating certain products, titanium in pigments, and antimonial lead (to a limited extent) for die castings.

The United States has been preeminent in the zinc industry of the world over a period of many years, even though its large resources are relatively low grade. This wealth of raw material more than supplied domestic demands until the middle 1930's and allowed an exportable surplus, but in 1935 consumption exceeded domestic production and, except for the period of industrial recession in 1938, has so remained. The result has been greatly increased imports, which in 1943 reached the all-time high of 593,143 short tons of zinc in concentrates, ore, and slab zinc.

[7] Bureau of Mines.
[8] Geological Survey.

The countries from which most zinc was imported during World War II, named in their order of importance, are Mexico, Canada, Peru, Newfoundland, Argentina, and Australia. Most of the zinc has come in as sulfide concentrates, which have been reduced to metallic zinc in American smelters.

The real acceleration in imports began in 1939 and has been due, in large part, to the relatively inflexible production capacity of most underground mines when confronted by a great and sudden increase in requirements. Mining capacities, involving the cross-section size of main entry tunnels and shafts, are geared to an expected rate of production over many years and in many instances do not permit sudden expansion. Moreover, elaborate and expensive concentrating plants, likewise geared to normal peacetime production, require

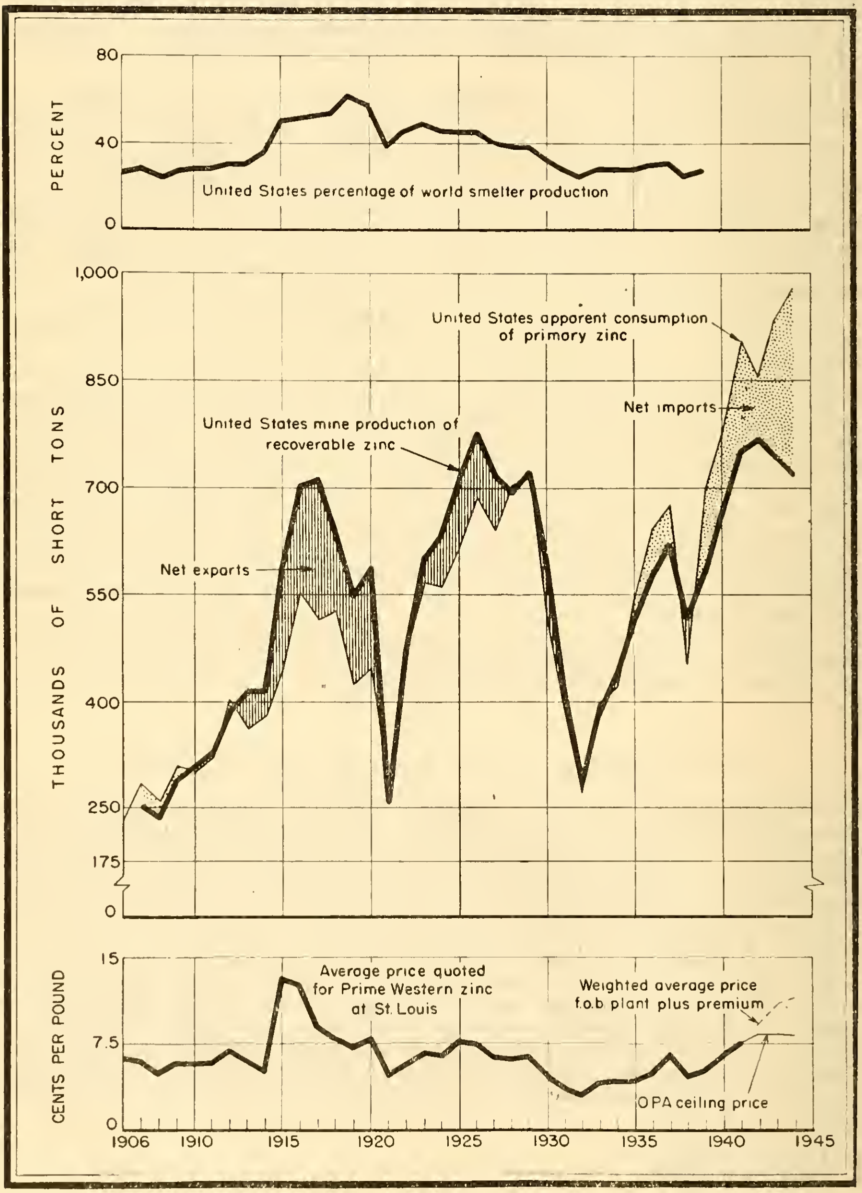


FIGURE 37.—Trends in production, consumption, and price of zinc in the United States, 1906–44.

time, materials, and manpower—all of which were short in the wartime emergency—if their capacities are to be increased. Acute mine-labor shortages also plagued the mining industry during the war.

The zinc-supply problem has been complicated by the depletion of reserves in the Tri-State region, which has dominated zinc production for approximately 70 years. Large facilities for both mining and milling will soon be idle in this district through exhaustion of the reserves.

In addition to depending upon imports to make up for deficiencies in production, efforts were made by the Government, beginning in 1942, to stimulate production by the payment of premium prices. Although a maximum of 16½ cents a pound was paid under the premium price plan, the average price in 1944 was 11.4 cents as contrasted with the long-term average price for zinc of 6 cents a pound. Until the advent of Government wartime control of zinc, conventional relationships between price, production, and consumption of zinc existed (see fig. 37). In 1942, following a 3-year period of rising price, consumption, and production, the complete allocation of refined zinc under control as to use resulted in lowered consumption; at the same time, the premium prices caused output to rise slightly to 766,025 short tons of recoverable zinc, but despite the continued effort to stimulate production, mine output decreased in 1943 and again in 1944, owing to depletion of ore in some districts and to acute labor shortages in others. In contrast, consumption advanced to nearly 1,000,000 tons in 1944, the highest point reached in the history of the domestic industry.

Table 40 lists the major zinc-producing districts or regions of the United States in the 5-year period 1940–44. These districts are commonly classed into three geographic groups—eastern, central, and western. These groups in recent years have been roughly equal in total annual output of metallic zinc. Most of the leading zinc districts yield a variable though usually subordinate percentage of lead which has to be taken into account in considering the economics of the different districts.

TABLE 40.—*Mine production of recoverable zinc in the United States, by districts that produced 1,000 tons or more during any year, 1940–44* (*slightly modified from Minerals Yearbook 1944*)

[In short tons]

District	State	1940	1941	1942	1943	1944
Tri-State region	Kansas, southwestern Missouri, Oklahoma.	232,437	258,837	237,936	200,514	190,270
Coeur d'Alene region	Idaho	62,948	68,321	78,313	79,634	85,227
Franklin	New Jersey	91,406	93,781	94,040	92,864	80,288
Central	New Mexico	29,573	34,649	42,374	52,215	44,648
Eastern Tennessee	Tennessee	34,796	36,170	[1] 43,971	[1] 41,766	40,831
St. Lawrence County	New York	35,686	38,446	45,807	46,000	35,541
Smelter (Lewis and Clark County).	Montana	14,462	18,751	20,190	24,165	20,623
Red Cliff	Colorado		10,880	22,880	28,854	20,492
West Mountain (Bingham)	Utah	21,812	20,496	22,634	23,405	19,151
Austinville	Virginia	[1] 16,927	[1] 22,913	15,793	17,139	18,257
Pioche	Nevada	10,773	14,391	8,957	11,991	17,983
Upper Mississippi Valley	Iowa, northern Illinois, Wisconsin.	5,776	7,956	11,126	15,539	17,242
Park City region	Utah	17,598	16,177	13,026	11,487	9,556
Metaline	Washington	11,560	14,201	13,620	9,292	9,236
Warren (Bisbee)	Arizona	1,812	2,095	1,449	1,020	8,070
Leadville	Colorado	172	48	3,344	5,512	7,984
Summit Valley (Butte)	Montana	35,899	38,070	29,313	7,877	7,874
Kentucky-Southern Illinois	Kentucky-southern Illinois	6,090	7,907	8,096	5,630	5,910
Pima	Arizona				1,390	5,170
Pioneer (Rico)	Colorado	2,607	3,008	2,764	3,652	4,557
Magdalena	New Mexico	206	2,580	3,185	5,290	4,474
Warm Springs	Idaho	7,104	8,534	6,260	4,740	4,000
Pioneer (Superior)	Arizona	3,175	4,139	3,884	4,072	3,850
Big Bug	do	1,740	1,804	2,650	3,009	3,794
Tintic	Utah	225	797	1,708	2,330	3,450
Hunter Valley	California					3,346
Old Hat (Oracle)	Arizona			579	2,450	2,521
Harshaw	do	2,714	3,531	4,825	3,398	2,051
Rush Valley	Utah	2,971	3,726	7,625	8,880	2,046
Flat Creek	California				229	1,532
Heddleston	Montana		548	1,266	953	1,529
Ten Mile	Colorado		70	643	971	1,483
Yankee Hill	California				407	1,444
Northport	Washington		103	685	914	1,438
Livingston	Virginia			198	1,456	1,410

TABLE 40.—*Mine production of recoverable zinc in the United States, by districts that produced 1,000 tons or more during any year, 1940–44 (slightly modified from Minerals Yearbook 1944)*—Continued

[In short tons]

District	State	1940	1941	1942	1943	1944
Packer Creek	Montana	------	------	------	1,001	1,389
Patagonia	Arizona	990	1,788	1,913	1,931	1,261
Chelan Lake	Washington	------	------	------	1,930	1,074
Sheridan	Montana	6	187	139	519	1,053
Wallapai	Arizona	4,295	2,346	2,244	1,542	1,046
Upper San Miguel	Colorado	------	------	390	1,215	828
Montana	Montana	713	1,474	489	203	755
South Mountain	Idaho	540	2,201	1,485	633	696
Animas	Colorado	1,394	832	379	474	576
Eagle	Montana	418	1,948	348	256	92

[1] Includes very small quantity produced elsewhere in State.

The eastern group includes the deposits of New York, New Jersey, Virginia, and Tennessee. Operations in these States are largely controlled by a few strong companies, and the deposits have been steady producers for many years. The ore mined near Franklin Furnace, N. J., averages between 14 and 21 percent of zinc and is therefore about the richest of the domestic sources, whereas some of the mines of eastern Tenenssee yield ore that contains less than 3 percent. At Ducktown, Tenn., the deposits contain only 1 to 1½ percent of zinc, but it is recovered as a byproduct of the ore, which is mined primarily for sulfur and copper. The Southern Appalachian region contains large pyrrhotite deposits in which the zinc content is only about 0.6 percent and which may or may not become workable under improved technology and price.

The zinc deposits in the Central States are in three areas—the Tri-State region, the Upper Mississippi Valley district, and the Southern Illinois-Kentucky district. Since 1871, the Tri-State region—embracing southwestern Missouri, southeastern Kansas, and, at a later date, northeastern Oklahoma—has dominated the American zinc picture; but by 1944, although it was still the most productive area, its percentage of the total domestic output had diminished to 26 percent from a high of 60 percent in the early 1920's. A large part of this decline has been due to depletion of reserves. The grade of ore mined has decreased steadily from what were at first rich ores, until in 1944 the crude ore from much of the district averaged only 2 percent of zinc. The deposits of the Upper Mississippi Valley district resemble those of the Tri-State region in grade, geologic occurrence, and diversity of ownership, but they are generally smaller and cannot be worked as cheaply; hence, for profitable operations, the grade of ore mined must be somewhat higher than in the Tri-State region. The zinc of the Southern Illinois-Kentucky district is closely associated with fluorspar, the production of which is comparable in value with that of the zinc. The zinc content is variable; in some mines it may amount to 17 percent, but in others it is little more than a byproduct of the fluorspar industry.

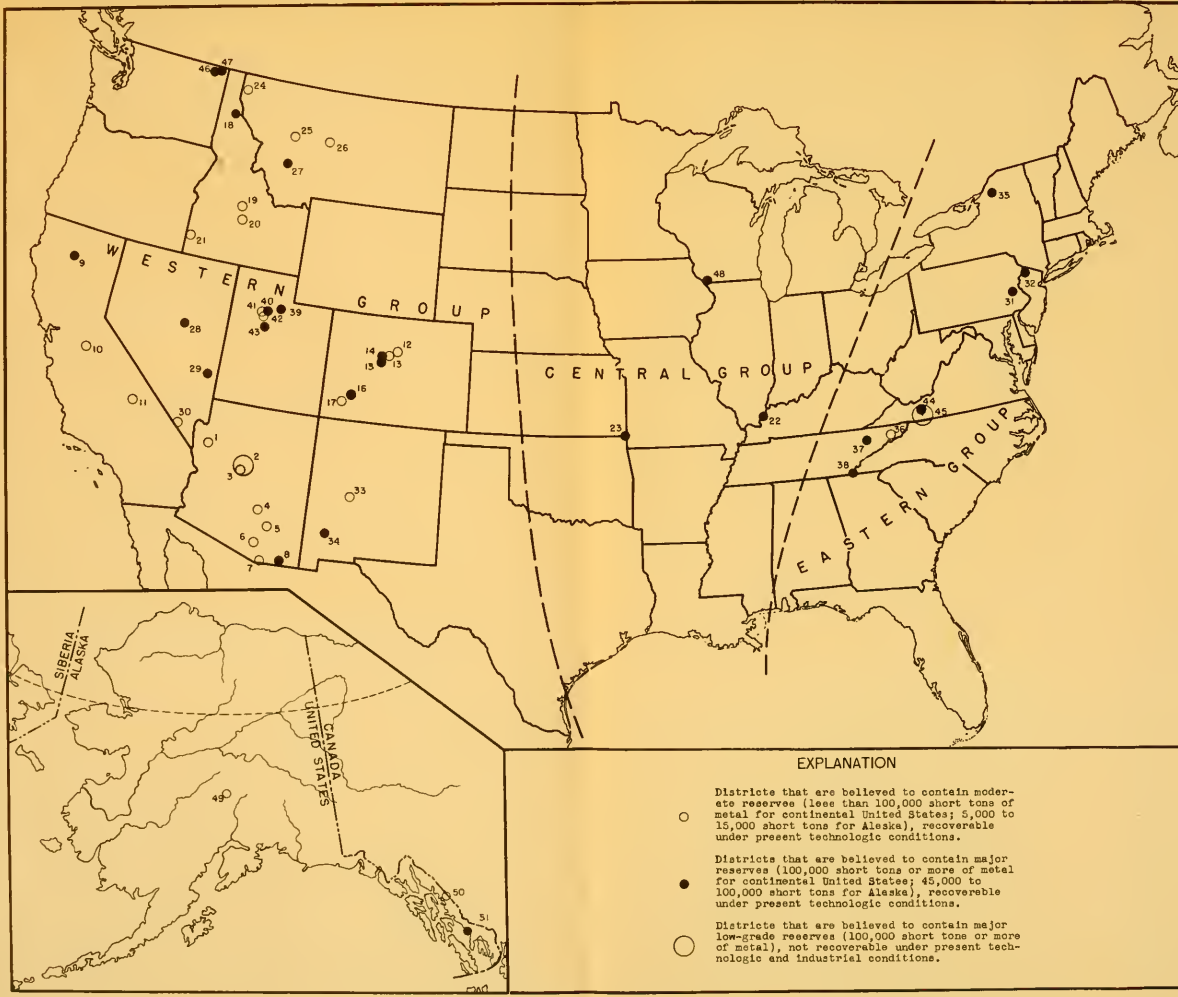
The deposits of the Western States, from the Rocky Mountains west, commonly contain lead and less commonly copper, as well as zinc, and a combined metal content of about 10 percent is usually necessary for profitable mining. The lowest grade of ore mined is in the Metaline district, Washington, where for large operations the average has been just below 6 percent of combined zinc and lead. Most western zinc-lead ores also contain substantial amounts of silver and a little gold; with increase of silver and gold content, the base-metal content can diminish proportionately and the ore still be commercial. The large pyrite deposits at Jerome, Ariz., contain zinc but have not been worked for lack of a market for the pyrite. In Shasta County, Calif., and elsewhere in the Western States, the zinc sulfide contains much iron and is difficult to treat under present smelting practices.

No zinc has yet been produced from Alaska, but low-grade deposits of moderate size are known in several areas, particularly on or near the mainland of southeastern Alaska. The most promising, in the Wrangell district, contains a considerable tonnage of ore that averages 8 percent of zinc, 1.5 percent of lead, and 1.5 ounces of silver per ton. A considerably larger tonnage in the same district contains only 2½ to 3½ percent of combined zinc and lead.

Reserves

Few reliable figures are available on the total reserves of zinc in different zinc districts in the United States. The largest mining companies for the most part

ZINC



EXPLANATION

○ Districts that are believed to contain moderate reserves (less than 100,000 short tons of metal for continental United States; 5,000 to 15,000 short tons for Alaska), recoverable under present technologic conditions.

● Districts that are believed to contain major reserves (100,000 short tons or more of metal for continental United States; 45,000 to 100,000 short tons for Alaska), recoverable under present technologic conditions.

◯ Districts that are believed to contain major low-grade reserves (100,000 short tons or more of metal), not recoverable under present technologic and industrial conditions.

DISTRICTS AND REGIONS CONTAINING ZINC RESERVES

ARIZONA
1. Wallapai district
2. Jerome district
3. Big Bug district
4. Superior district
5. Mammoth district
6. Pima district
7. Harshaw and Patagonia districts
8. Bisbee district

CALIFORNIA
9. Shasta County
10. Foothill Belt
11. Darwin district

COLORADO
12. Silver Plume district
13. Kokomo district
14. Red Cliff district
15. Leadville district
16. San Juan region
17. Rico district

IDAHO
18. Coeur d'Alene region
19. Boulder Creek and Bayhorse districts
20. Warm Springs district
21. South Mountain district

ILLINOIS
22. Southern Illinois-Kentucky district

KANSAS (-Missouri-Oklahoma)
23. Tri-State region

MISSOURI (-Kansas-Oklahoma)
23. Tri-State region

MONTANA
24. Troy and Libby districts
25. Heddleston district
26. Barker district
27. Butte district

NEVADA
28. Eureka district
29. Pioche district
30. Goodsprings district

OKLAHOMA (-Kansas-Missouri)
23. Tri-State region

PENNSYLVANIA
31. Friedensville district

NEW JERSEY
32. Franklin district

NEW MEXICO
33. Magdalena district
34. Central district

NEW YORK
35. St. Lawrence County

TENNESSEE
36. Embreeville district
37. Eastern Tennessee (sulfide deposits)
38. Ducktown district

UTAH
39. Park City district
40. Bingham district
41. Rush Valley district
42. Ophir district
43. Tintic district

VIRGINIA
44. Austinville district
45. Gossan Lead Belt

WASHINGTON
46. Northport and Colville districts
47. Metaline district

WISCONSIN (-Illinois-Iowa)
48. Upper Mississippi Valley district

ALASKA
49. Mt. Eielson district
50. Tracy Arm
51. Wrangell district

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CHART XXIX.—Distribution of reserves of zinc in the United States and Alaska as of January 1944, by districts and regions.

keep their figures confidential, and because of inherent complexities in the form and grade of the ore bodies the reserves cannot be even roughly approximated by anyone who does not have access to company maps and assay data. Furthermore the usual practices of developing ore only 1 to 5 years ahead means that the company figures, even when available, generally show only the measured and indicated ore, making no reference to ore that may be inferred in geologically favorable but unexplored ground.

Table 41 summarizes the estimated reserves of known zinc-bearing areas of the United States in two classes, depending on whether the material can be mined (*a*) under technologic conditions similar to those in 1944; and (*b*) under possible future conditions. Reserves that could be mined under technologic conditions obtaining in 1944 are subdivided into (1) reserves that could be mined under normal economic conditions as reflected in the price of zinc in relation to production costs (6-cent zinc in the 20-year period from 1921 to 1940); (2) additional reserves that could be mined only under more favorable economic conditions, assuming a cost-price spread somewhat better than normal; and (3) additional reserves that become available only under abnormal conditions similar to those of 1942–44, wherein prices of 13¾ to 16½ cents for zinc and 9¼ to 12 cents for associated lead were received by operators of deposits of this class.

Chart XXIX shows the geographic location of the reserves estimated. About 14,400,000 short tons of zinc—measured, indicated, and inferred—is in ore or tailings that can be worked under normal economic conditions; about 77 percent of this zinc (11,200,000 tons) is recoverable. This zinc must compete with imports of foreign ores, but all of it probably will be available in time. About 5,300,000 tons more is in ore that should be workable under more favorable economic conditions. The zinc in high-cost camps and in some slag piles at lead smelters, considered available only at the higher wartime premium prices, is believed to be only slightly more than 2,000,000 tons. Zinc in pyritic deposits and in most slag piles constitutes the material that would be available only under improved technologic conditions.

The estimate of reserves includes a considerable tonnage of low-grade ore in the Tri-State region that can be mined under the premium prices of 1944; but because of underground water, parts of this reserve may be lost forever if the district remains idle for any appreciable time before this ore is extracted.

The estimate does not include inferred reserves in districts not yet discovered or in known districts whose zinc potentialities have not yet been realized, hence it is a minimum that will undoubtedly be augmented by such factors to an unknown extent.

Alaska's reserves—which as now known amount to only 122,000 tons of metal, indicated, and inferred, in all categories of ore—are not included in table 41

TABLE 41.—*Estimated zinc reserves of the United States as of January 1944*

[In short tons of metallic zinc]

	Measured and indicated [1]		Inferred [2]		Total [2]	
	Gross content in ground	Recoverable content [3]	Gross content in ground	Recoverable content [3]	Gross content in ground	Recoverable content [3]
(*a*) Zinc in deposits that could be worked under technologic conditions similar to those in 1944:						
1. Under normal economic conditions [4]	6, 957, 000	5, 400, 000	7, 500, 000	5, 800, 000	14, 400, 000	11, 200, 000
2. Additional, under somewhat more favorable economic conditions	1, 961, 000	1. 500, 000	3, 300, 000	2, 500, 000	5, 300, 000	4, 000, 000
3. Additional, under emergency prices	1, 295, 000	1, 000, 000	900, 000	700, 000	2, 200, 000	1, 700, 000
Total	10, 213, 000	7, 900, 000	11, 700, 000	9, 000, 000	21, 900, 000	16, 900, 000
(*b*) Zinc in deposits workable under possible future technologic or industrial conditions	3, 721, 000		400, 000		4, 100, 000	

[1] This includes individual estimates of measured and indicated ore in some properties where such ore is known, but for which the tonnage figures are unavailable.
[2] Figures rounded.
[3] Milling and smelting losses are considered to be roughly 23 percent.
[4] Price equivalent to 6 cents per pound and prewar costs.

because of the uncertainty as to how they should be classified economically. The richest deposits, which are only a few miles from the coast near Wrangell, contain a possible 45,000 tons of zinc and perhaps could be worked at the higher premium prices under economic and technologic conditions of 1944. Most of the other known deposits are too low-grade, considering their location, to be worked profitably at any predictable future price.

Without regard for price and productive capacity, the zinc recoverable from measured and indicated ore by present technologic methods is equivalent to the domestic needs of this country for 12 years at a minimum peacetime rate of consumption of 650,000 tons of zinc per year. The additional inferred reserves in known districts should add another 14 years. With the exhaustion of a good part of the Tri-State reserves, mine, mill, and smelter-production capacities will have to be increased in other districts if the average annual requirements are to be filled largely from domestic sources. In peacetime, when material, labor, and time are available for such expansions, the adjustments should offer no serious problems. The two districts believed to hold most promise for making up the deficit due to depletion of the Tri-State region are Eastern Tenneseee and Northeastern Washington.

With a demonstrated wartime need of about 1,000,000 tons of zinc annually, and assuming that productive capacity is suitably maintained and premium prices are possible, domestic reserves as now known appear to be adequate to insure a substantial domestic output for any war emergency within the next 2 to 3 decades. It appears probable, however, that a predictable dependence on foreign sources for some zinc in the normal postwar years will almost inevitably be increased in any future war period. The zinc resources of Mexico and Canada appear ample to supply a large share of such potential demands through rail-borne imports.

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